Wetlands as Nature-Based Solution in Mitigating the Impacts of Climate Change-induced (Compounding) Hazards:

A Case Study of Raised Bogs in Bargerveen

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A Case Study of Raised Bogs in Bargerveen

Master Thesis Water Systems and Global Change Group in partial fulfilment of the degree of Master of Science in the master program Climate Studies at Wageningen University, the Netherlands

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Abstract

Climate change will increase the frequency and intensity of future extreme weather events in the Netherlands. Wetlands, particularly raised bogs, play an important role in mitigating the impacts of extreme weather events, such as floods, droughts, wildfires, and heatwaves, and this role in disaster risk management is still underexplored. This study examined a function of recovered raised bog in Bargerveen located on the border between the Netherlands and Germany as a NbS in disaster risk management for mitigating the impacts of compounding hazards. This study employed various methodologies, including literature review, historical and future hydrometeorological data analysis, groundwater level and statistical modelling, policy evaluation, and a survey. Future projections indicate a warmer and drier climate, leading to a decline in groundwater levels, which may further challenge water availability and wetland restoration. The results indicate that Bargerveen could contribute significantly to resilience against various (compounding) hazards by regulating water levels in times of drought and flood, mitigating heatwaves, and reducing the risk of wildfires. However, its full effectiveness depends on continued restoration and conservation efforts, integrated water management, and cross-border collaboration. Moreover, integrating Bargerveen into disaster risk management strategies requires a coordinated and collaborative policy approach that balances raised bog restoration with regional priorities.

Key words: Nature-based Solutions, Wetlands, Bargerveen, Disaster Risk Management, Hazards

Table of Contents

1. Introduction

1.1 Background

The functioning and significance of wetlands have been studied for several decades. However, it was not until the early 2000s, that wetlands were recognized and regularly studied as a valuable nature-based solution (NbS). Particularly for their role in mitigating environmental challenges such as flood control and coastal protection (Millennium Ecosystem Assessment, 2005). Later, studies focusing on wetlands as mitigating multiple hazards, or in some cases compounding hazards, have been conducted. For example, studies on flood and drought mitigation, or flood control and water quality (Ferreira et al., 2023; Lui et al., 2023).

These mitigating qualities are useful, especially in an increasingly volatile climate. The effects and impacts of global warming are becoming more prevalent and evident. According to recent studies on the risk of weather-related hazards in Europe, climate change enhances the risk of climate hazards (Forzieri et al., 2016; Forzieri et al., 2017). This applies to hazards such as droughts, floods, heat waves, wildfires, and water quality issues. Wetlands can serve as a so-called buffer zone for climate hazards, by reducing, for example, the duration and severity of droughts or enhancing the resilience to floods (Ferreira et al., 2023). Moreover, they can improve the water quality by filtering pollutants (Lui et al., 2023). All these qualities highlight the multifunctionality of these ecosystems in addressing complex urban and environmental issues.

There is a variety of types of wetlands around the world. Wetlands are diverse ecosystems characterized by water saturation either permanently or seasonally, and they include a wide range of types (Verhoeven, 1992). The different types of wetlands serve different functions in their respective ecosystems. According to the United States Environmental Protection Agency (EPA), there are four different types of wetlands. These are marshes, swamps, bogs, and fens (EPA, n.d.). The Canadian Wetland Classification System classifies five different types adding shallow water as its own category (National Wetland Working Group, 1997). Some sources also allocate peatland as its own category. However, peatlands encompass bogs and fens (Kellner, 2003). These ecosystems are vital for maintaining biodiversity, regulating water flow, and sequestering carbon (Joosten & Clarke, 2002; Verhoeven, 1992). Marshes are typically found along rivers and lakes, dominated by grasses, reeds, and other herbaceous plants (EPA, n.d.). Swamps, on the other hand, are wetlands dominated by trees and shrubs and are often found in forested areas with nutrient-rich soils (EPA, n.d.). Bogs and fens represent a unique subset of wetlands that differ based on their water sources and vegetation (Joosten & Clarke, 2002). Fens receive water from both precipitation and groundwater, making them more nutrient-rich, while bogs rely solely on rainwater, leading to acidic conditions and low nutrient availability (Joosten & Clarke, 2002).

Peatlands, including both bogs and fens, are defined by the accumulation of peat, which forms when plant material, such as mosses, sedges, and shrubs, decays slowly in waterlogged, anaerobic conditions (Verhoeven, 1992). The key distinction between peat and bogs lies in their characteristics: **peat** refers to the partially decomposed organic material that accumulates in wetland environments, while **bogs** are a specific type of peatland ecosystem (Joosten & Clarke, 2002). The lack of nutrients supports the growth of specialized plants like *sphagnum* moss, which plays a crucial role in peat formation. Peatlands, whether bogs or fens, are important carbon sinks, but the nutrient-poor, acidic conditions of bogs make them particularly significant for long-term carbon storage (Joosten & Clarke, 2002).

This study's focus is on bogs, particularly the raised peat bog in the Netherlands, specifically Bargerveen. Peat bogs have been integral to the Netherlands' environmental and economic history for over a millennium. Originally, these bogs covered large parts of the country, particularly in the northern provinces and along the coast (Verhoeven, 1992). From the Middle Ages onward, peat extraction became a vital industry, as peat served as the primary fuel source for domestic use and urban industries, leading to widespread peatland degradation

(Joosten & Clarke, 2002). The Dutch developed advanced water management systems, including ditches and windmills, to drain the peatlands for agriculture and habitation, further accelerating peatland loss (Verhoeven, 1992). This process, while economically advantageous, resulted in severe ecological consequences, including land subsidence and increased flood vulnerability. By the late 19th century, the extensive exploitation of peat bogs had greatly diminished these ecosystems. Today, only fragments of the original peat bogs remain, and modern conservation efforts aim to restore these areas for their ecological functions, particularly as carbon sinks (Verhoeven, 1992; Joosten & Clarke, 2002).

Bargerveen is one of the last remaining bogs in Western Europe. It has a very diverse biodiversity, with, for example, the Great Sundew (plant), which is important for a variety of rare birds (Bargerveen Schoonebeek, n.d.). The peat bogs in Bargerveen have been part of a nature-based solutions project to restore and enhance the ecological integrity of this vital peatland area in addressing key environmental challenges such as climate change, biodiversity loss, and water management. The primary aim of the project is to improve the resilience of the Bargerveen ecosystem by restoring its natural hydrology and vegetation, thereby increasing carbon sequestration and promoting biodiversity (Hooijer et al., 2010). Key objectives include re-wetting degraded peatlands, implementing sustainable land-use practices, and engaging local communities in conservation efforts.

However, a critical component that has not been fully integrated into the NbS framework is hazard mitigation, particularly in relation to the increasing risks associated with extreme weather events. Incorporating strategies for flood risk management and soil erosion control into the Bargerveen project could enhance the overall effectiveness of the NbS approach, providing multiple benefits for both ecological resilience and local communities (Zhang et al., 2018). By explicitly linking hazard mitigation with nature-based solutions, stakeholders can develop a comprehensive management strategy that not only fosters biodiversity and carbon storage but also protects communities from the adverse impacts of climate change.

1.2 Problem statement

As one of the many consequences of anthropogenic climate change, the Netherlands is experiencing more frequent and more severe extreme weather events (Botzen et al., 2008). In the climate scenarios report by the KNMI in 2014, they predicted that in winter, precipitation and temperatures will both increase. Whereas in the summer, precipitation overall will decrease but the amount of rain per event will increase, leading to more extreme rainfall events, and potentially more flooding. These extreme weather events pose a threat now and in the future. After the European flood of 2021, which was caused by extreme rainfall, it was concluded that the Netherlands is not (yet) well prepared for such events (National Delta Programme, 2022). To be better equipped, nature-based solutions can be used, such as wetlands, to mitigate the potential impacts.

Understanding the role of nature-based solutions in disaster risk management is crucial for developing effective strategies to mitigate the impacts of natural hazards and climate change. nature-based solutions consist of natural processes and ecosystems, such as wetlands, forests, and coastal systems, to enhance resilience against disasters like floods, landslides, and storm surges. By integrating ecological approaches into disaster risk management, researchers can identify how healthy ecosystems contribute to hazard mitigation, such as by absorbing excess rainwater, stabilizing soils, and providing barriers against storm impacts. Additionally, this research helps to highlight the importance of biodiversity and ecosystem health in maintaining the services that protect communities from disasters. Furthermore, understanding these dynamics facilitates the development of policies that promote sustainable land use and conservation practices, ensuring that natural landscapes are preserved and restored to effectively reduce vulnerability and enhance community resilience in the face of increasing environmental threats.

Despite the growing recognition of nature-based solutions as effective strategies for enhancing disaster risk management, there are still significant knowledge gaps about their specific roles and effectiveness in various contexts. Additionally, there is a lack of comprehensive frameworks that integrate nature-based solutions into existing disaster risk management policies, highlighting the need for further studies to explore how these solutions can be systematically incorporated into mainstream disaster resilience planning.

This study aims to address these gaps by using a case study in Bargerveen. Therefore, the objective of this thesis is to understand to what extent wetlands, particularly raised bog, can function as nature-based solutions in disaster risk management for mitigating the impacts of compounding hazards. Moreover, this thesis explores how to optimize the effectiveness of these nature-based solutions to reduce the impacts of compound hazards in the Dutch/German nature reserve Bargerveen. Lastly, the findings of this study will be used to advise on a cross-border risk management policy.

2. Research objectives and research questions

This study aims to address the research gap on the role of nature-based solutions in disaster risk management. The objective of this study is to understand to what extent wetlands, particularly raised bog in Bargerveen, can function as nature-based solutions in disaster risk management for mitigating the impacts of climate change-induced hazards. Moreover, the effect of compounding hazards on the role of raised bogs as NbS is studied. This thesis explores how to optimize the effectiveness of these nature-based solutions to reduce the impacts of hazards in the Dutch/German nature reserve Bargerveen. Lastly, the findings of this study are used to advise on a cross-border risk management policy. To achieve its objective, this study elaborates main research question as described below:

> **'How can wetland ecosystems be utilized in disaster risk management to mitigate the impacts of compound natural hazards exacerbated by climate change?'**

The main question above is refined into the following five research questions:

(1) What is the current ecological and hydrometeorological state of Bargerveen?
(2) To what extent can wetlands, particularly raised bogs, function as nature-based solutions for mitigating the impacts of (compounding) hazards?
(3) How can the effectiveness of these nature-based solutions be optimized for Bargerveen?
(4) How can the findings of this study inform disaster risk management policy development for Bargerveen and similar nature reserves?
(5) How does the local community perceive the social and economic role of Bargerveen, and how might these perceptions influence the use of wetlands in disaster risk management?

3. Theoretical framework

In this chapter, the theoretical framework will be presented. This includes a description of the scientific field, and a description of the relevant concepts used in this study.

3.1 Nature-based solutions

Nature-based solutions is broadly defined as "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions." (European Commission, n.d.-a). The International Union for Conservation of Nature (IUCN) (2016) defines NbS as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.". Wetlands or peatlands can be used as nature-based solutions to help build resilience against different types of hazards and provide environmental benefits, as discussed in the wetland section (chapter 3.3). Wetlands can also provide social benefits, as the nature reserve can be used recreationally.

3.2 The various climate change-induced hazards

3.2.1. Floods

Floods in the Netherlands are often caused by above-normal precipitation or rapid snowmelt upstream in the rivers. Climate change has caused the likelihood and severity of extreme weather events, such as extreme rain, to increase, which increases precipitation-generated flooding (Tradowsky et al., 2023; Kundzewicz et al., 2014). As climate change causes warming air, which can hold more moisture, it can lead to more intense rainfall, and thus more flooding (Kreienkamp et al., 2021). This was also what caused the July 2021 floods in north-western Europe (Tradowsky et al., 2023). Floods occur when the ground becomes saturated and can no longer absorb additional water, resulting in excess water flowing to other areas (Kundzewicz et al., 2014).

3.2.2. Dry hazards: Droughts, Heatwaves, and Wildfires

In addition to flooding, droughts, heatwaves, and wildfires are so-called 'dry' hazards. They share common origins, specifically below normal precipitation and elevated temperature (Sutanto et al., 2020). A drought is characterized by a prolonged deficit in precipitation relative to normal, combined with elevated evaporation rates, resulting in a situation where the water lost through evaporation exceeds that of water received through precipitation (KNMI, n.d. -a). A recent study conducted following the severe drought of summer 2018 in the Netherlands revealed that the increasing frequency of droughts is attributed to global climate change (Philip et al., 2020b). Heatwaves are defined in the Netherlands by the KNMI as a series of a minimum of five days with a temperature over 25 degrees Celsius, of which at least three are above 30 degrees Celsius, measures in De Bilt (KNMI, n.d. -b). Wildfires are unplanned and/or unwanted natural or human-caused fires in a natural area, such as a forest or grassland, as defined by the Federal Emergency Management Agency in the US (FEMA, n.d.). After the record-breaking heatwave of 2019 in Europe, studies were conducted on the link between climate change and the frequency and intensity of heatwaves. They found that heatwaves in Europe are more likely to occur and more intense due to human-induced climate change (Oldenborgh et al., 2020; Vautard et al., 2020).

3.2.3. Compounding and cascading hazards

This study will look at different climate change-induced hazards that could be mitigated with the use of ecosystem services of a wetland. The hazards that are of importance in this study are floods, droughts, heatwaves, and wildfires. These hazards could occur on their own and will then be called 'single' hazards. The hazardous events can also follow each other. If two or more extreme events take place in a sequence or accumulate over time, without any break between them, so with no 'hazard-free days' in between, one refers to 'cascading' hazards (Sutanto et al., 2020). So, the disasters occur in succession, but the direct impacts need to overlap to be considered consecutive disasters (de Ruiter et al., 2020). Natural hazards are called 'compounding' hazards when two or more events occur simultaneously, so in the same region and on the same day (Lui & Huang. 2014). The events can be either dependent or independent hazards. 'Independent' hazards are "whose impacts spatially and/or temporally overlap while the hazards themselves are neither triggered by one another nor do they influence one another's probability of occurrence" (de Ruiter et al., 2019, p. 3). 'Dependent' hazards are the opposite. The impacts of cascading and compounding hazards are greater than those of single hazards as independent events (Lui et al., 2016).

For this study specifically, compounding hazards could include situations where both a heatwave, wildfires and a drought occur simultaneously. These events are all exacerbated by (extreme) warm temperatures and little to no precipitation over a longer time span. In the summer of 2018, the longest regional heatwave took place in the Netherlands, while at the same time, the country suffered from a drought (KNMI, 2019; Philip et al., 2020a). These two hazards or events are dependent hazards since they were both triggered by abnormally high temperatures and little to no precipitation for an extended period. Moreover, CBS (Central Bureau for Statistics) (2019) concluded that there were 70 percent more warnings for roadside fires and double the number of warnings for wildfires compared to the year before.

3.3 Wetlands and raised bogs

The word 'wetlands' has many different definitions, as there is no globally set definition. One definition is: "A wetland is an ecosystem that arises when inundation by water produces soils dominated by anaerobic processes, which, in turn, forces the biota, particularly rooted plants, to adapt to flooding" (Keddy, 2010, p. 2). The Oxford Dictionary just states "an area of land that is usually saturated with water, often a marsh or swamp". (Oxford University Press, n.d.). They are, thus, a sort of transition zone between aquatic and terrestrial ecosystems. Wetlands can be found on every continent and cover roughly 6 percent of the land surface on earth (Maltby, 1988; Davidson et al., 2018). Wetlands provide many ecosystem services. For example, provisioning services such as food, fibre, and water, regulating services such as flood control, climate regulation, and erosion protection, supporting services such as nutrient cycling, and cultural services such as recreation (MEA, 2005). Wetlands, specifically peatlands, also store a lot of carbon. Peatlands are wetland ecosystems with a layer of partially decomposed organic matter, which is stored in their soil (Strack et al., 2022). Peatlands store 20-30 percent of the global total soil carbon stock, while only accounting for 3 percent of the terrestrial surface (Leifeild & Menichetti., 2018; Strack et al., 2022). However, damaged peatlands, which are only about 0.3 percent of the earth's land surface, account for 50 percent of land CO_2 emissions, and 5 percent of total global annual CO_2 emissions (Bonn et al, 2016). Thus, degrading or degraded peatlands is a major issue.

Bargerveen is a peat (raised) bog. A bog is an "acid nutrient-poor peat area, developed under the influence of precipitation" (Haslam, 2003, p. 4). A raised bog, according to the author, is a "rain-fed and growing above another wetland type" area (p. 6). The other wetland type can be, among others, an infilled lake, flood plain, or blanket bog. However, most bog systems in the Netherlands have lost their raised bog characteristics due to extensive peat cutting, drainage, and burning (Tomassen et al., 2010).

According to multiple studies, wetlands can serve as buffer zones, or natural sponges, by absorbing excess water and releasing it slowly, thus reducing the peak flood intensity (Bullock & Acreman., 2003). This can enhance the resilience to floods (Ferreira et al., 2023). Furthermore, Wu et al. (2023a) studied the mitigation abilities of wetlands to droughts and concluded "wetlands mainly contribute to alleviating hydrological droughts by decelerating the development process, accelerating the recovery, shortening the duration, and reducing the severity of the hydrological drought events" (p. 2). Moreover, they concluded that wetlands can "weaken the transition of meteorological to hydrological droughts" (p. 2). Thus, wetlands help mitigate drought impacts, as a reduction in rain does not immediately affect water bodies, groundwater, and soil moisture. (Wet) peatlands can increase resilience to wildfires, due to their moisture retention, which helps to mitigate the frequency and severity of wildfires (Kettride et al., 2017). This is only true for well-maintained or restored peatlands, as drained peatlands are highly susceptible to (wild)fires (Kettridge et al., 2017).

Lastly, according to Worrall et al. (2020), intact or restored peatlands can mitigate regional heatwaves due to climate warming by creating a localized cooling effect. This is due to their moisture-retaining properties. Their ability to store water provides regional climate regulation benefits. These peatland ecosystems function as so-called 'cool islands' in their landscapes, reducing temperatures in their vicinity, especially during heatwaves. Important to note is, however, they also found that shrub-dominated peatlands do not exhibit the same 'cool island' effect, since the energy balance and albedo are different (Worrall et al., 2020). This disrupts the cooling and moisture-retaining properties and thus their ability to moderate temperatures for their surroundings.

3.4 Disaster Risk Management

To be able to manage and decrease the risk involved with natural hazards, risk must first be defined. The IPCC (2020, p. 4) defines risk as "the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems". When risk is mentioned in the context of climate change, risks form due to the interaction between climate change-induced hazards, exposure, and vulnerability (IPCC, 2020). As previously discussed, the hazard types discussed in this study are adversely affected by climate change. Exposure might also be affected due to, among others, urbanization and land-use change. In addition, vulnerability can be affected by a change in socio-economic factors, such as poverty or access to resources, specifically for elderly and low-income households. The focus of this thesis is how risk can be reduced by affecting the hazard with wetlands as NbS.

Risk management is "Plans, actions, strategies or policies to reduce the likelihood and/or magnitude of adverse potential consequences, based on assessed or perceived risks", according to the IPCC (2020, p. 5). Meanwhile, the definition of disaster risk management (DRM) from the United Nations Office for Disaster Risk Reduction (UNDRR, n.d.-a) is "disaster risk management is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses" (n.d.-a). Both share a common goal of risk reduction and enhancing resilience, but DRM is more specific to disasters. There are different approaches or types of DRM, with the most relevant approaches being the corrective disaster risk management and the prospective disaster risk management. Corrective disaster risk management focuses on reducing existing risks, such as floods and droughts (UNDRR, n.d.-a). Wetlands have different capacities to help reduce these risks. This study could also fall into the prospective disaster risk management approach since the aim is to prevent future risks from intensifying as climate change worsens (UNDRR, n.d.-a).

3.5 Current scientific field

For this research, it is relevant to know and understand what has recently, or is currently, being researched on (similar) topics. For instance, what is being researched in Bargerveen, or the most recent findings in studies on using wetlands as a NbS. nature-based solutions involve using natural processes and ecosystems to address environmental challenges (European Commission, 2015). This concept will be further discussed in chapter 3.4.

Research on Bargerveen is relatively limited. Most research is focused on restoration and conservation, as for example, the report by Versluijs et al. (2020). This Dutch report explores habitat development in Bargerveen, focussing on expanding active raised bog, promoting peat formation, and restoration measures. Similarly, Hesselink (2019, p. v) wrote his master thesis on the potential of implementing "the productive use of wet peatlands by agriculture, to support the restoration of the raised bog ecosystem and to create a regenerative raised bog landscape". In 2008, a report was written by *Staatsbosbeheer* (State Forest Management) on raised bog restoration for Bargerveen. There has also been made an environmental impact assessment on the use of buffer zones surrounding the nature reserve, with the aim of benefitting water management, and in turn, nature itself (MER, 2021).

Meanwhile, there are plenty of (recent) studies on the use of wetlands as a nature-based solution, mostly for water management. Recent studies research the use of wetlands to reduce floods, droughts, and pollutants (Ferreira et al., 2023). Many more papers on similar topics exist, such as "Nature-based Systems (NbS) for mitigation of stormwater and air pollution in urban areas" (Biswal et al., 2022). They use bioretention systems, green roofs, and wetlands as nature-based solutions for mitigation of urban environmental issues. Aside from water management, papers and studies also mention or focus on the use of wetlands to store carbon, either by storing extra carbon or by reducing the amount of CO_2 emitted by the wetlands/peatlands. For example, the paper by Bonn et al. specifically on peatland ecosystem services (2016), "Wetlands, carbon, and climate change" by Mitsch et al. (2012), or Strack et al. (2022) on peatlands as nature-based solutions.

4. Methods

The full methodology used in this study is presented in detail in Figure 1. The five different colours indicate my five sub-questions, for two sub-questions, more than one method is used to answer the question. The results from research questions 1 until 4 are used to form part of the basis for the questionnaire questions. Moreover, the results from the first two questions are used to answer question 3. The study area, data collection processes, and the methodologies are explained in the following sections.

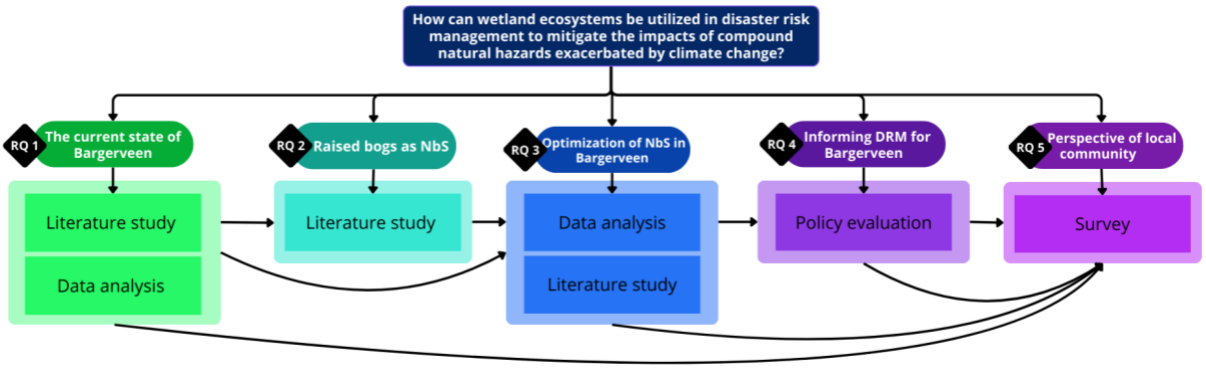

Figure 1. Methodology in a graphic presentation.

4.1 Study area

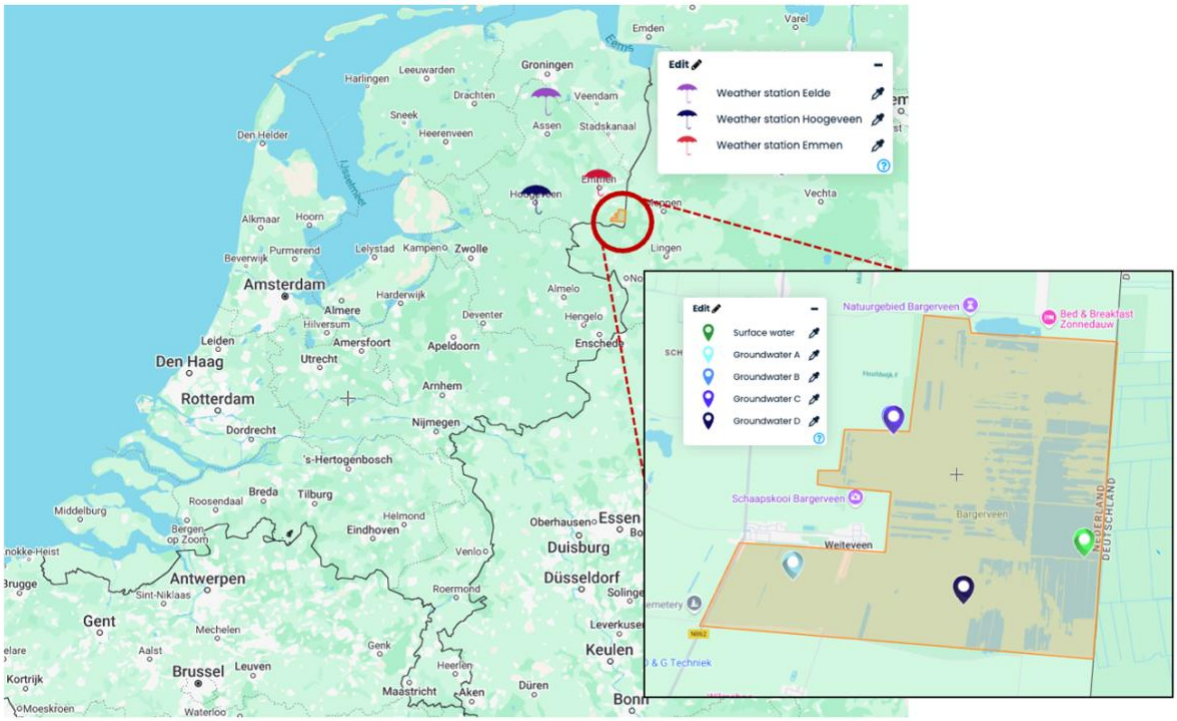

Figure 2. An overview of the study area (Bargerveen), including the data collection points of the surface water, groundwater, and the weather data.

This study focusses on the nature reserve Bargerveen. It is located in the south-east of the Dutch province Drenthe near Emmen, It spans between the Netherlands and Germany, meaning that the region requires cross-border environmental management and cooperation, as shown in Figure 2. On the Dutch side, the State forestry department (*Staatsbosbeheer*), has ownership of the nature reserve and since 2006 it has been part of the International Nature Park Veenland (*Internationaal Natuurpark Veenland*) (Bargerveen Schoonebeek, n.d.).This raised bog is the last remaining one in the Netherlands (Provincie Drenthe, 2023). The region formerly belonged to a much bigger wetland called Bourgangerveen, or Bourtanger Moor in German,

which was almost completely extracted for fuel until 1992 (Provincie Drenthe, 2023). In Germany, extraction of peat is still occurring to this day (Provincie Drenthe, 2023). Bargerveen did not exist until 1987, and when it was formed, it was only a small area compared to its current size (Kadaster, n.d.). Bargerveen as it is today, was formed in 2005, as shown in the images below (Fig. 3). Up until 2004, the rest of the area was called Amsterdamsche Veld.

After extraction stopped in the NL, big parts of the region are being rewetted, in an effort to conserve and restore the wetland. The Dutch part (Bargerveen) is a Natura 2000 area, as shown in the map below. Natura 2000 areas are protected regions under the Bird (2009/47/EC) or Habitat (1992/43/EC) directive (Ministerie van LVVN, n.d.).

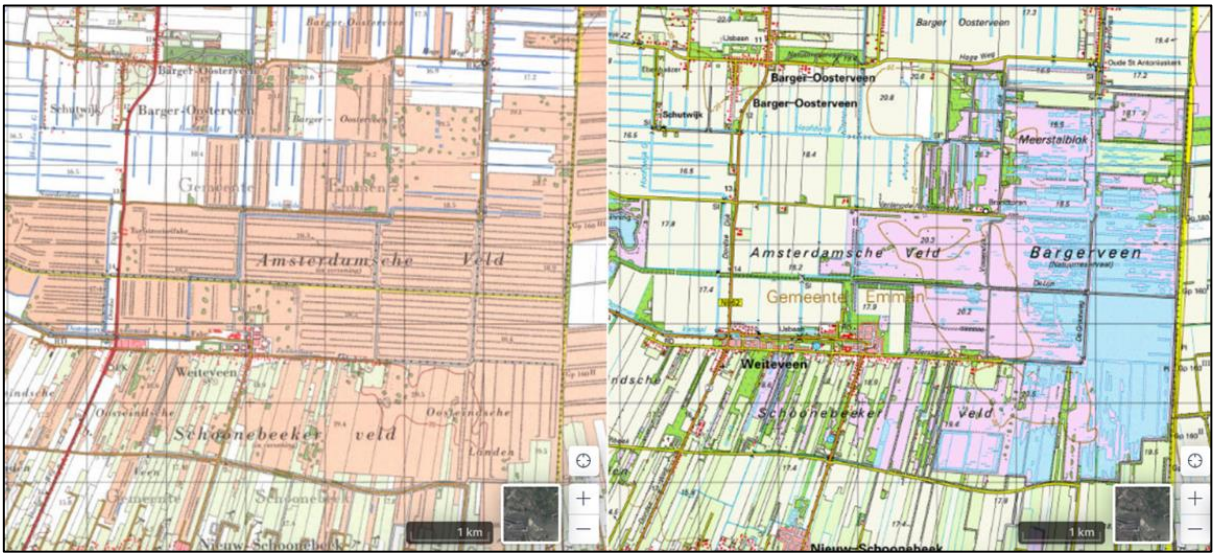

Figure 3. The area of nature reserve Bargerveen. On the left is the map of the situation in 1987. On the right is the situation in 2005. Images made on Topotijdreis (Kadaster, n.d.)

Bargerveen spans 2.096 ha, in which there is a range of peat extraction in different sections (Provincie Drenthe, 2019). A report on Bargerveen in 2019 classified approximately 1.600 ha as recovering Raised bog (Provincie Drenthe). In the map below (figure 4), the brown areas on the map of Bargerveen highlight the recovering raised bog. The digital terrain model (*Actueel Hoogtebestand Nederland,* AHN) shows that the reserve varies between approximately 17 and 20 meters above sea level (AHN, n.d.).

Figure 4. Map of Bargerveen, showing the recovering raised bog areas, retrieved from Provincie Drenthe, 2023.

The German part of the raised bog

In the image below (Figure 5), the current situation across the German border can be seen. It seems like the old Bourtanger Moor is protected, as it is covered in either pink or red.

However, the status of Naturpark in Germany in itself does not carry any legal restrictions or protection. Only if the area also has a *naturschutzgebiet* (NSG), *landschaftsschutzgebiet* (LSG), or Natura 2000 status, is it truly protected. Only the red areas have a NSG status, thus only small parts of the old Bourtanger Moor on the German side are protected. A more detailed description of the regulations is given in Chapter 5.4. The nature park is called Internationaler Naturpark Bourtanger-Moor. This park, together with Bargerveen, was included in the transboundary program of Europarc Federation from 2021 onwards, where they focused on cross-border collaboration between protected areas (Europarc, 2021). However, both the German and the Dutch side have resigned from this program (Europarc, personal communication, January 20, 2025).

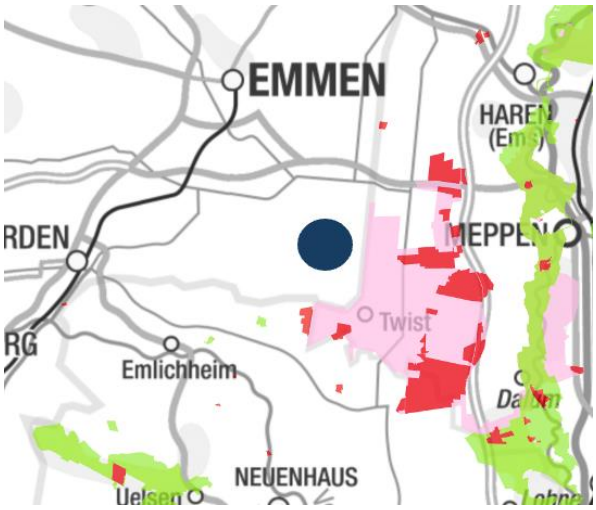

Figure 5. Environment/nature map on the German side retrieved from Niedersachsen ministry for the environment, Energy and Climate protection. *Blue indicates Bargerveen on the Dutch side, pink indicates Naturpark, red indicates Naturschutzgebiet (NSG), Green indicates Landschaftsschutzgebiet (LSG), and light grey indicates the border between the countries.*

4.2 Data collection

4.2.1 Literature reviews

The literature research was performed using Google Scholar and Web of Science. In these databases, a combination of terms was searched, alternating with query language terms (OR and AND). The terms varied per research question. To understand how wetlands can function as NbS, the following terms were used: Wetlands, Raised Bog, Wetland, Peatland, NbS, (natural) hazards, Climate change, Floods, Wildfires, Droughts, Mitigation, Impacts, Ecosystem services, Compounding, Cascading. This provided the information needed to explain how wetlands can help to mitigate the impacts of such hazards. The terms used to answer research question 3 on how to optimize the NbS in Bargerveen were as follows: Peatland, Raised bog, Germany, The Netherlands, Wetland, Optimization, Effectiveness, NbS, Floods, Drought, Heatwave, Wildfire, DRM. To obtain an overview of the state of Bargerveen, the following terms were used: Bargerveen, Peatland, Raised bog, Germany, The Netherlands, Natura 2000. For this sub chapter, much of the relevant information is found in policy documents, reports, and governmental websites rather than academic papers. Therefore, Google was additionally used to access grey literature.

4.2.2 Trend analysis and modelling

To understand the hydrometeorological state of Bargerveen for question 1, a trend analysis of local temperature and precipitation was performed. For this, three datasets were assessed, their locations can be seen in Figure 2. The first dataset from the KNMI from one of their major weather stations in Eelde, located about 52 km away. This dataset provides the daily mean temperature (in 0.1 C°) and the daily precipitation amount (in 0.1 mm) from 1957-2024.

Data on temperature started in 1907, but since precipitation was not measured until 1957, this year was chosen. The second dataset is obtained from the KNMI station Hoogeveen, located 35 km away from the study site. The KNMI warns to not perform trend analysis with this dataset, since it is not homogenised. For this reason, a shorter timeframe was chosen, 1994-2024, to avoid problems arising from the non-homogenised data. A paper on Bargerveen by Tomassen et al. (2022) also used this dataset. The last dataset was acquired from an independent weather station in Emmen, approximately 11 km away. This dataset consists of monthly average temperature data (1.0 C°) and monthly precipitation data (1.0 mm), and ranges from 2008-2024. This weather station uses reliable equipment and was, therefore, deemed fit to use.

To optimize the effectiveness of nature-based solutions in Bargerveen, it is crucial to understand how future groundwater levels will respond to climate change. High and stable groundwater levels are needed for a healthy raised bog, which is, in turn, needed for it to successfully function as a NbS. The aim of the data analysis for question 3 was to make a predictive model that simulates groundwater levels under various future climate scenarios. For this, five different variables were needed: temperature, precipitation, humidity, surface water level, and groundwater level data. The data on precipitation, temperature and humidity came from the weather station from KNMI in Hoogeveen. Most of the groundwater and surface water level data came from the Data and Information on the Dutch Subsurface Office (DINO). One dataset on groundwater was acquired from the authors of a study on the acrotelm forming in raised bogs in the Netherlands, Tomassen et al (2022). The data analysis was done using SPSS. To make subsequent graphs, Python3 was used.

The model utilized four climate scenarios, provided by the KNMI. These scenarios vary based on future CO_2 emission levels (Low versus High) and future climate conditions, specifically whether the climate tends towards increased aridity (d) or greater moisture (n), i.e. experiencing more droughts of higher levels of (excessive) rainfall (KNMI, 2023). The four scenarios are further explained in the table (Table 1) below. The KNMI provides transformed time series of weather data for all four scenarios for the period 1991-2020 for Hoogeveen weather station. These datasets were used in the modelling of future groundwater levels.

Table 1 The changes in climate in the different scenarios. (KNMI, n.d.). Ld indicates low emission level and increased aridity, Ln indicates low emission level and greater moisture levels, Hd indicates high emission level and increased aridity, and Hn indicates high emission level and greater moisture levels

Variable	Climate in 1991-2020	Ld (2100)	Ln (2100)	Hd (2100)	Hn (2100)
Temperature in Celsius (daily average)	10.5°C	+ 0.9°C	+0.9°C	+4.4°C	+4.1°C
Precipitation in mm (yearly average)	851	0%	+3%	-3%	+8%
Relative Humidity (daily average)	82%	-1%	-1%	-1%	+1%

Among the many surface water datasets acquired, only four out of approximately 50 provided daily water level measurements, while the rest included measurements taken only twice a month. Since all other variables in the model have daily data, the four daily datasets were chosen. One of these datasets had a much higher correlation with the groundwater points (Spearman's rho of 0.9 vs 0.2/0.3), than the others, so this surface water level dataset was used for the modelling. This dataset is called P23A00111. The exact location where the surface- and groundwater levels are measured, can be seen figure 2.

For the analysis, four different groundwater datasets were used, which vary in location within Bargerveen (Figure 2). Six datasets were acquired originally, however, one set had data from 1994-2004, which makes this data not reliable for the actual groundwater levels in Bargerveen after restoration efforts started, hence it was not used. The other dataset that was not used, only had data from 2018-2020, which was too short to make a model with. This dataset was from Tomassen et al. (2022). The final datasets used were A (B23A0411), B

(B23A0452001), C (B23A0452001), and D (B23A0461). For each of these four datasets, a model was created to simulate daily groundwater levels under the four scenarios. This process resulted in a total of 16 modelled datasets, as each dataset was modelled separately for each scenario. The same method was applied to all four datasets.

4.2.3 Policy evaluation

A review of relevant legislative and policy documents from the Netherlands, Germany and the European Union (and other international legislation) was conducted, focussing on environmental conservation, ecosystem services, cross-border nature management, and biodiversity protection. Relevant policies were identified through a review of literature, policy documents, and official reports at local, national, and EU levels. For EU and other international policies, the following directives are mentioned: *The Habitat Directive, The Birds Directive, The EIA Directive, Civil Protection Mechanism, Floods Directive, Water Framework Directive, Biodiversity Strategy for 2030, Strategy on Adaptation to Climate Change, Paris Agreement, the Ramsar Convention, and the Sendai Framework*. The Dutch policies are *Environment and Planning Act (Omgevingswet), Safety Regions Act (Wet veiligheidsregio's), Climate act (Klimaatwet), Provincial environmental regulation Drenthe (Provinciale omgevingsverordening Drenthe), Nature management plans Drenthe (Natuurbeheerplannen), and Environmental and Planning Drenthe (Omgevingsvisie Drenthe).* The German policies are *Federal Nature Conservation Act (Bundesnaturschutzgesetz), Lower Saxony Nature Conservation Act (Naturschutzgesetz), Regulation Dalum-Wietmarscher Moor (Verordnung), Federal Spatial Planning Act (Raumordnungsgsetz).* This gave an overview of the current policies that are applicable to Bargerveen.

4.2.4 Survey

An assessment of the social and economic perspectives of residents on Bargerveen was made using a survey. This questionnaire was made using Google Forms. The survey consisted of four sections. Section 1 purely asked for consent. Section 2 was about personal information, such as where the respondents live, how long they have lived near Bargerveen, and how often they visit the nature reserve. Section 3 contained questions on their experiences and perspectives on Bargerveen. For example, what advantages or disadvantages does Bargerveen present for the community, what their concerns are for future developments in Bargerveen, and how important it is to include the community in decisions. It was not possible to ask direct questions on using Bargerveen for climate adaptation, as the province was worried that people would think it was an actual ongoing project by them and not a hypothetical thesis topic. Lastly, section four asked if they were open to a follow-up phone call, if they would like a copy of the results of the survey, and if they have any final remarks. The full survey is included in annex C. Google Forms was used for easy distribution. This link was shared in the December 2024 news brief of Bargerveen-Schoonebeek, via Prolander, on December 18th. The survey was also shared on the official Facebook page of Zwartemeer, on December 22nd.

4.3 Data analysis

4.3.1 Trend analysis of meteorological data

The Spearman's rho test in SPSS was applied to detect (monotonic) trends within the environmental variables. This helped to identify whether the variables were significantly increasing, decreasing, or remaining stable over time, providing insights into the meteorological trends at Bargerveen. The Spearman's rho test is commonly recommended for climatological or hydrological trend analysis (Yue et al., 2002). In the study by Yue et al. (2002), they compared the Mann-Kendall and Spearman's rho test. They were found to be indistinguishable in practice. Spearman rho test, unlike the Mann-Kendall test, can be performed in SPSS and was, thus, chosen for this study. The test was 1-tailed since the direction of the trend is already

hypothesized, namely positive/increasing for temperature and negative/decreasing for precipitation, as discussed in previous chapters. The significance level was set at 95%.

The data was also presented in a scatterplot with a trendline, to indicate a trend and provide a R^2 value to explain what part of the variation in the data is explained by, in this case, time. The Spearman's rho test and the scatterplots were employed for both precipitation and temperature, with the original data and detrended data. This was done to see if the seasonality has an influence. All data was detrended, by calculating the average of each month type, for instance, the average of all January data, and subtracting that from the values. This was done for both the temperature and the precipitation data.

A Standardized Precipitation Index (SPI, McKee et al., 1993) was used to characterize the meteorological conditions of Bargerveen. This method is commonly used to analyse drought occurrences, but it can also be used to identify wet and dry conditions of a particular region. The daily precipitation data from Hoogeveen was adapted to monthly data. This provided 30 years of monthly precipitation data, which is the timeframe needed for such analyses according to the World Meteorological Organization (WMO, 2012). Both SPI-6 and SPI-12 were used, as these give an impression of the hydrological and groundwater drought (WMO, 2012). SPI-6 uses a six-month accumulation data, whereas SPI-12 uses a twelve-month accumulation data. The WMO (2012) classifies the SPI values as displayed in Table 2 (p. 4).

Table 2 SPI values and classifications according to the WMO (2012).

SPI values	Classification
2 and over	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	(near) Normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

With the use of the four groundwater datasets, a scatterplot with trendlines was made to indicate if a trend in water levels could be detected.

4.3.2 Groundwater modelling

The method for the groundwater modelling had four main steps. The first step was to check the correlation between the four independent variables and the dependent variable, namely groundwater (GW). This was done with Spearman's test since the data is not normally distributed. The test was 1-tailed since the direction of the correlation was hypothesized. The significance level was set at 95%. The correlation was checked mainly to be sure that the relationship between the variables was significant. If not, the independent variable may not be used in the later formulated equation to predict GW.

Step two was to perform a linear regression with the dependent and independent variables. Here, the focus was on the R-square value, the B-coefficients and the respective significance values. The coefficients, if significant, were used to create the formula used to predict GW levels (Eq. 1). This step involved using a filter to ensure that only dates with complete data were included.

$$\boldsymbol{GW} = A - (B * T) + (C * P) + (D * H) - (E * SW) \qquad (1)$$

A, B, C, D, and E = Unstandardized coefficient B of their respective variable
T = Temperature
P = Precipitation
H = Humidity
SW = Surface water level

Step three was to validate the model. This was done by splitting the database, to make a trial dataset and a test dataset. Exactly where the dataset was split depended on the model, since the GW datasets have different timelines. For example, the model could be split into 2013-2016 (trial) and 2017-2018 (test). With the trial dataset, a linear regression was performed to create the equation (Eq. 1). This equation was then used to calculate the GW levels of the test set. The predicted GW levels are then compared to the actual GW levels, with a correlation test and a residuals test. The residuals were calculated by subtracting the predicted levels from the actual levels. The residuals were then plotted in a histogram to see the distribution and the mean. The distribution should be normal, and the mean should be around 0.

Step four used the equation acquired in step two to predict the GW levels under the different scenarios. For this, the transformed time series data on temperature, precipitation and humidity were used. Moreover, the surface water (SW) level data was predicted for the four scenarios using the same method as for the GW levels, but only with temperature, precipitation and humidity. So, a correlation test, linear regression test, and validation were performed to get the SW level data for each scenario. This way, the SW level was also dependent on the other variables, rather than making it a constant. A constant did not work, since the predicted GW levels turned out too dependent on the constant, rather than on the other variables.

This resulted in 16 predicted GW levels. The average was calculated for easy comparison between the scenarios and data points, using descriptives in SPSS. Moreover, line graphs with trendlines were made using Python3.

4.3.3 Policy analysis

To answer the research question on how the findings of this study can inform disaster risk management policy development for Bargerveen and similar nature reserves, a policy analysis was conducted. The aim of this policy analysis was to understand the primary focus or objective and assess the impact of the relevant policies on using Bargerveen as NbS. Browne et al. (2019) describes a similar aim of policy analysis.

4.3.4 Survey

The results of the survey on the local perspectives were analysed in three different ways. First, the direct conclusions from each question were analysed. For example, what percentage of people responded that they visit Bargerveen often, or what percentage of people think it is important to include residents in decision-making processes. Second, a Spearman correlation test was performed in SPSS on the closed-ended questions, i.e. all questions that had an answer on a scale from 1-5. A Spearman correlation test was chosen since all variables are ordinal. Third, a thematic analysis was done on the four multiple-choice questions. Respondents were able to choose multiple answers and fill in their own answers. These questions were on their perceived advantages and disadvantages of living close to Bargerveen, and their concerns and positive expectations for the future of Bargerveen.

To determine how many responses the survey should get to be representative of the population, it was first established how large the potential respondent group is. In a study done by Wageningen University and Research on the perception and recreational use of nature in the Netherlands, people were interviewed living close to their chosen nature reserves, with a maximum distance of 5 km (de Vries, 2009). Since this study had a similar topic, the same distance was used. A circle with a 5 km radius, with Bargerveen in the middle, was made to determine the relevant villages and neighbourhoods. The exact area can be seen in Annex B. Some of the circle is on German territory and was not added to the total population, since they are not in the potential respondent group.

The villages included are Zwartemeer, Barger-Oosterveen, Weiteveen, and Nieuw-Schoonebeek. Using the 2023 neighbourhood database from the Central Agency for Statistics (CBS) on PDOK, the exact population size could be determined. This resulted in 6915 people that live within 5 km of Bargerveen. Since children are not expected to answer the survey, and

thus do not fall in the potential respondent group, they are removed from the list. In 2024 in the municipality of Emmen, where this region belongs to, 17.3 per cent of the population is under 18 (CBS, n.d.). Hence, the final potential respondent group was 5719 people.

Then, the margin of error and confidence interval were set. The margin of error, or level of precision, is how close the sample estimate is to the true population value (Isreal, 1992). For studies on subjective opinions, like this survey, exact precision is not crucial, hence a relatively large margin of error (8-10%) (Bryman, 2016). A confidence interval is the range where the true population value is likely to fall, based on a specified confidence level (Isreal, 1992). In social science research, where the focus is detecting general patterns and sentiments, a 90% confidence level is commonly used, to be reliable while keeping the sample size manageable (Bryman, 2016). These choices, with the potential respondent group size, were submitted to the online sample size calculator (SurveyMonkey). The sample size needed to give a reliable and accurate view of the perceptions of the local population is 68 to 105 people, depending on the margin of error.

5. Results

5.1 Ecological and hydrometeorological state of Bargerveen

5.1.1 Contextual and Academic Review

On Topotijdreis, a website with 200 years of topographical maps of the Netherlands, yearly satellite maps can be found, starting in 2006. These were used to analyse the differences in appearance of Bargerveen over the years. A few years or images were remarkable. There is not much of a difference in the images from 2006 until 2012. There is, however, a striking difference between the images of 2012 and 2013, as shown in Figure 6. This difference could be caused by more either plant/peat moss/algae growth in the water, which can give the appearance of less water. Or there was less water in 2013 due to, for example, a drought that year. There is, however, no information on a potential extensive drought in 2013. Moreover, the images are made, according to the Dutch land registry (Kadaster) between mid-February to mid-April, whereas droughts mostly occur in (late) summer in the NL. The images are always made in the 'leafless seasons'. However, in 2014 they started constructing buffer zones around Bargerveen, aimed at keeping the water in (Deltanieuws 03, 2024). Since Bargerveen lies relatively high, compared to its surroundings, the water would disappear without dikes or buffer zones (Tomassen et al, 2023). The image of 2014 resembles the situation of 2012 (and before). This supports the theory that the difference in the images is due to a lack of water, rather than new plant or peat growth.

Figure 6. Satellite images of Bargerveen. Left: 2012, right: 2013. Retrieved from Topotijdreis (Kadaster).

Up until 2018, the images are similar again. In Figure 7, the difference between 2018 and 2019 can be seen. The image of 2019 shows either a drier situation or more plant/peat/algae growth. Both appear to be true in this instance. From the summer of 2018 onwards, until 2019, it was exceptionally dry in the region (Provincie Drenthe, 2023; Tomassen et al, 2022). Additionally, because of the dry years, more algae growth had occurred in the recovering raised bog. This is not positive for the restoration process, as the peat becomes more nutrient-rich, which increases the risk for grassification and forestation (Provincie Drenthe, 2023). Moreover, alive peat moss will die due to the anaerobic circumstances. Hence, an adequate groundwater level, and thus precipitation level, is needed to recover the raised bog. The groundwater levels have gotten better over the years, mainly due to the construction of buffer zones that cause counterpressure (Provincie Drenthe, 2023). However, the groundwater levels are not yet stable, which is also vital for a healthy raised bog (Provincie Drenthe, 2023). The water level should be level to a peat or sand level (Tomassen et al., 2022).

Figure 7. Satellite images of Bargerveen. Left: 2018, right: 2019. Retrieved from Topotijdreis (Kadaster).

In an intact and undisturbed raised bog, the top layer of living and deceased *Sphagnum* moss, known as the acrotelm, significantly contributed to maintaining a stable hydrological balance (Tomassen et al., 2022). Thus, *Sphagnum* moss is important for a fully functioning system, but not all types of moss work in this ecosystem. Only mound-forming species of *Sphagnum* moss possess these characteristics, as they grow above the water level in the peat, and the organic material of mound-forming moss decomposes more slowly (Tomassen et al., 2022). Specifically for the Netherlands, five types would work, and these are crucial for raised bog recovery (Joosten, 1995; Tomassen et al., 2005). The six types are *Sphagnum fuscum, S. rubellum, S. magellanicum, S. papillosum,* and *S. affine* (Tomassen et al., 2022). In Bargerveen, the main type of moss is *Sphagnum cuspidatum* (Tomassen et al., 2003). This species is disposed easier compared to the five named species, and barely grows above the water level (Tomassen et al., 2022). Hence, this type does not create an acrotelm, which is needed for a fully functioning raised bog. When these favourable types of moss are hardly or no longer present, it is unlikely that they will appear spontaneously (Tomassen et al., 2022). Hence, its spread mainly depends on vegetative reproduction from planted fragments.

However, even in hydrologically favourable conditions, establishing these types of moss can still be challenging in Bargerveen, as they do not perform well when the nitrogen levels in the soil are high (Tomassen et al., 2022). In the Netherlands, the critical value of nitrogen (500 mol/ha/year) is exceeded massively. In 2022, the nitrogen deposition was, on average, 1375 mol N/ha (CLO, 2024). However, the yearly nitrogen deposition has decreased slightly in the last decades, so it is improving, but not enough yet, especially for highly sensitive ecosystems such as raised bogs (RIVM, n.d; CLO, 2024). With the use of the buffer zones on all sides, except the border with Germany, the deposition of nitrogen in the ecosystem is already lessened.

The current ecological and hydrological challenges in Bargerveen mainly consist of raising and stabilizing the water level, introducing and maintaining the correct type of moss, and nitrogen deposition. The concern surrounding the nitrogen levels in the Netherlands, and specifically in Bargerveen, also came forth in the survey that was conducted for the last sub-question. One person mentioned nitrogen as a worry for future developments in Bargerveen, and another highlighted the importance of mentioning nitrogen in this study.

5.1.2 Trend analysis of Bargerveen's climate and groundwater levels

The following trends in temperature, precipitation, and SPI provide context for the ecological and hydrometeorological state of Bargerveen. The raised bog depends on stable

hydrological conditions, which may be impacted by these climate shifts, affecting the restoration process.

Only the results from the weather station in Emmen will be presented and discussed, since all the results show similar strengths of trends. The results of the other weather stations are included in the annex E. A Spearman's rho test (1-tailed) was performed on both the original data and the detrended data. The exact results are presented in Table 3. The correlation coefficient indicates a negative/decreasing trend for precipitation over time, and a positive/increasing trend for temperature. This is in line with the earlier statements made in this thesis. The coefficient is stronger with the detrended data, hence without seasonality the trend is more significant. The trends for all data, except the precipitation over time, are statistically significant.

Table 3 Results from the Spearman's rho tests and R^2 Linear value from scatterplots for precipitation and temperature. *Red indicates a significance level of under 95%.*

Variable 1	Variable 2	Spearman's rho	p-value	R^2 Linear
Time	Precipitation	-0.105	0.068	0.021
Time	Temperature	0.120	0.045	0.012
Time	Detrended Precipitation	-0.122	0.043	0.024
Time	Detrended Temperature	0.333	<0.001	0.102

The scatterplots with linear fit trend lines also indicate the same direction in trend in both the original and detrended data. The R^2 Linear value, retrieved from the scatterplots, indicates how much of the variation in temperature or precipitation is explained by time. All R^2 values are shown in Table 3. This value increases for the detrended test, in comparison to the original test. For example, for temperature 1.2% of variation can be explained by time, versus 10.2% with the detrended data. The scatterplots figures can be found in the annex E.

With the precipitation data from Hoogeveen (1995-2024), two SPI plots, SPI-6 and SPI-12, were made and presented below (Figures 8 and 9, respectively). The SPI-6 identified 12 dry events in Hoogeveen with values below -0.99, indicating moderate dry periods. Meanwhile, the SPI-12 graph shows only six dry events, suggesting that using longer periods smooths out some variability. As this indicates fewer but longer dry periods. Figure 8 shows short-term drought events (SPI-6), which appear more frequent but less prolonged compared to long-term events in Figure 9 (SPI-12).

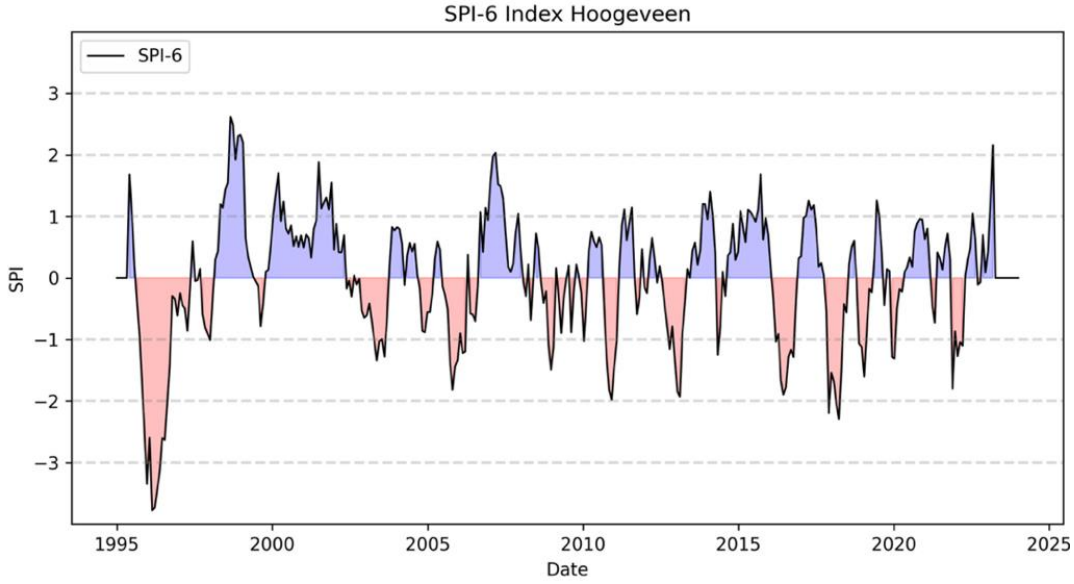

Figure 8. SPI-6 from monthly precipitation from Hoogeveen (1995-2024).

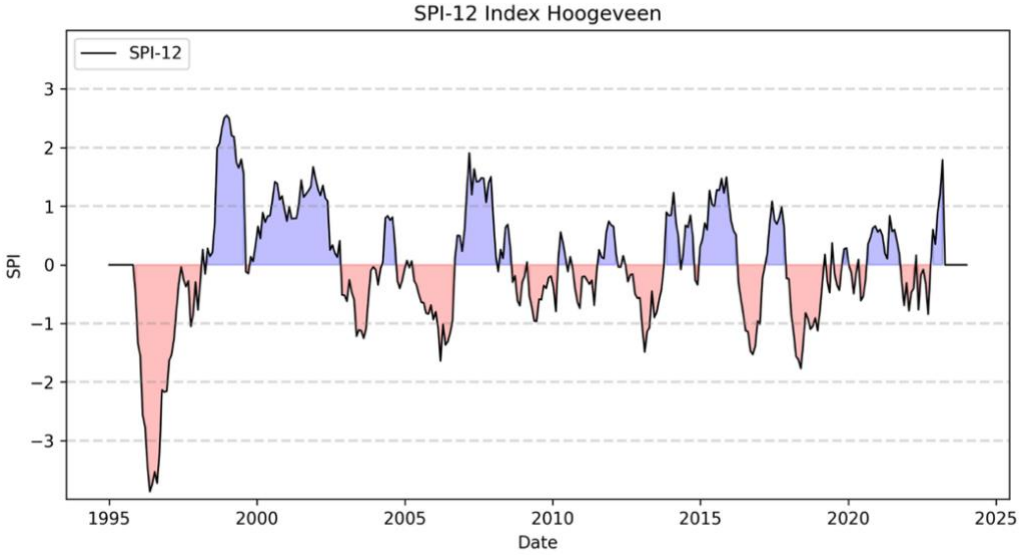

Figure 9. SPI-12 from monthly precipitation from Hoogeveen (1995-2024).

Groundwater levels

The groundwater levels of four measurement points were analysed to see if there was a significant trend. Unfortunately, the results are inconclusive. Two datasets show a positive trend, one shows a negative trend, and the last one remains stable over time. The figure is in annex D. However, the province reported long-term monitoring results that did indicate that the groundwater level has increased in Bargerveen, due to the added buffer zones (Provincie Drenthe, 2023). For the purposes of this thesis, it is assumed that this trend is accurate, which report long-term monitoring results and indicate that restoration efforts have contributed to a rising groundwater level in the area. The groundwater level is not yet stable though, as concluded by Provincie Drenthe (2023).

5.2 Raised bogs as a NbS for mitigating the impact of (compounding) hazards

The mitigating effects, or ecosystem services, provided by wetlands are diverse, each contributing to their role as NbS for hazard mitigation. This study elicits the potential role of raised bogs as a NbS for mitigating the impact of compounding hazards with detail presented below.

5.2.1 Floods

The role of wetlands in regulating hydrological cycles and increase the resilience to floods has been widely and scientifically recognised. Wetlands could maximise its function as natural sponges during period of heavy rainfall or snowmelt and retain the water to release it slowly reduces the peak flow and risk of flooding downstream (Finna, 2023; Bullock and Acreman, 2023).

There are five characteristics of wetlands that determine the mitigating impact wetlands can have on floods (Acreman & Holden, 2013). First, the landscape location and configuration are critical. Downstream wetlands have a greater potential to reduce floods, than upstream ones. Wetlands that are not directly connected to rivers, such as Bargerveen, may hold and capture (local) rainfall and runoff, and mitigate floods that way, though explicably have little influence on river floods. Second, the topography of the wetland plays a role; ridges and depressions increase water retention potential. Third, different soil characteristics affect the ability to absorb water and control the speed of water movement through the soil. Specifically, the coarser the soil is, the faster water can move through it. Fourth, the soil moisture status affects flood attenuation. Wetlands with already saturated soils prior to a flood have reduced capacity to absorb additional (flood)water. Whereas drier wetlands have a greater potential to store water. The flood mitigation ability also depends on the morphology of the wetland. Wetlands with

more capacity of soil drainage and evapotranspiration are more effective at reducing flood risk. Fifth, the management of the wetland contributes to the mitigating impact. For instance, draining (upland) wetlands can increase runoff. Moreover, vegetation removal can decrease friction and accelerates water flow, reducing the mitigating impact. Lowering water levels during potential floods, however, can improve the water storage potential. Although, this could impact wetland conservation or restoration efforts.

Downstream wetlands are more effective at managing floods and droughts than upstream ones (Wu et al., 2023b). The paper of Acreman & Holden (2013) differentiates between upland rain-fed wetlands and downstream river-fed wetlands. They state that there are numerous ways in which wetlands can impact floods. Wetlands can alter the peak flow, the lag/rise time, the volume of a flood, and the duration of a flood. In the figure below (Figure 10), these different characteristics are described in a flood hydrograph, as well as an example hydrograph of the impact of a wetland on a flood. The peak flow describes the maximum flood level, and thus what area gets flooded (Acreman & Holden, 2013). By retaining water in wetlands, the peak flow can be reduced, thus diminishing the exposure of nearby areas to flooding. The rise time indicates the time it takes for the flood water to rise, and how quickly the peak flow is reached (Acreman & Holden, 2013). By slowly releasing retained water, this time is lengthened, increasing the time to warn people and act, consequently, reducing the exposure and vulnerability. The same applies to the lag time between rainfall and peak flow. The flood volume can be reduced, if the wetland holds the water indefinitely, or at least until the flood has occurred. Lastly, the duration of the flood can be altered, depending on how long the wetland retains the water and how slowly the water is released. It is important to note that the direction of influence of wetlands on floods can also be negative (Acreman & Holden, 2013).

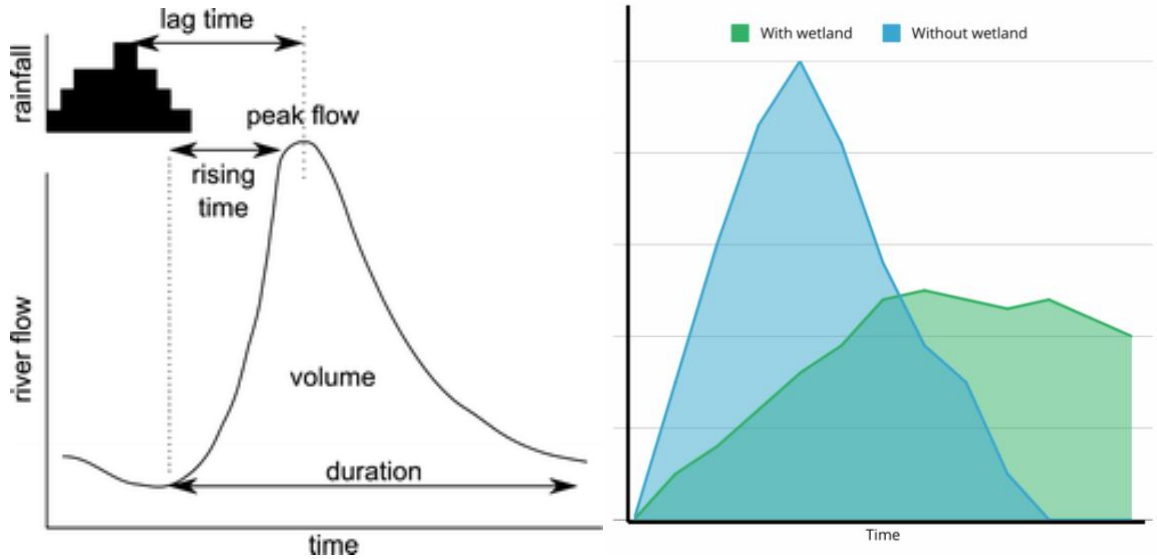

Figure 10. Hydrograph on river floods (Acreman & Holden, 2013) and an example hydrograph of a flood with and without the mitigating impacts of a wetland.

However, Bargerveen is not situated near major rivers, nor is it upstream. Bargerveen can be classified as an isolated wetland, as it is self-contained and not connected to rivers or streams, as it only relies on precipitation. Although its capacity to reduce flood risks remains relevant due to its role in regulating local hydrology. Raised bogs like Bargerveen are effective at absorbing and storing rainwater, which they release gradually over time (Acreman & Holden, 2013). This is due to the type of moss that grows in (raised) bogs, namely *Sphagnum* moss (Gauthier et al., 2022; Waddington et al., 2011). This is most prominent after long dry periods (Bragg, 2002). These isolated wetlands stabilize water tables and contribute to localized flood prevention, which is increasingly important considering climate change increases rainfall

intensity and frequency (Wu et al., 2023b; Government of Ireland, 2024). The mitigating impacts, as with a lot of other ecosystem services they provide, only work in well-preserved or restored wetlands (Finna, 2023).

5.2.2 Dry hazards: Droughts, Heatwaves, and Wildfires

Wetlands help mitigate droughts as they play a key role in slowing the progression of hydrological droughts, promoting quicker recovery, and decreasing the duration and intensity of droughts (Wu et al., 2023a; Endter-Wada et al., 2020). The paper by Wu et al, (2023a) also highlights that wetlands can buffer the transition from meteorological to hydrological drought. In this way, wetlands reduce the immediate impact of rainfall shortages, as this does not instantly affect surrounding water bodies, groundwater, and soil moisture (Wu et al., 2023a). Thus, providing a natural resilience against drought conditions for the region.

However, isolated wetlands could also potentially worsen drought conditions (Wu et al., 2023b). Wu et al. (2023b) also state that isolated wetlands do contribute to drought mitigation, especially ones in the lower part of bigger basins. Moreover, their advice is to conserve and restore mainly wetlands in middle- and lower-basin, as they reduce drought risk, but also flood risk, most significantly.

Wetlands evaporate more water than other land types (Bullock & Acreman, 2003). Hence, they are described by a higher humidity level than the surrounding land, leading to creation of cloudiness and mist over the area (Hesslerová, 2019). More cloudiness and mist over the area leads to a local cooling effect, since more solar radiation (heat) is blocked or reflected. The higher evaporation and evapotranspiration rates from wetlands also create more latent heat transfer, cooling the area further. Accordingly, Hesslerová et al. (2019, p. 83) wrote "wetlands reduce the temperature due to the cooling effect of evapotranspiration and the shading effect of cloudiness and fog that are created by the evaporation of water."

So, wetlands, such as raised bogs, can mitigate (local) heatwaves due to its cooling effect. Worrall et al. (2020) concluded the same, stating that intact or restored peatlands can alleviate heatwaves by creating a cooling effect due to their role in the hydrological cycle. However, this only works when the wetland is *not* shrub dominated, since shrubs and similar vegetation types disrupt the energy balance and changes the albedo, losing the ability to moderate temperatures (Worrall et al., 2020). Furthermore, removal and destruction of wetlands alters precipitation patterns, since a reduction in precipitation is found when these ecosystems are changed (Hesslerová, 2019). Consequently, recovering wetlands such as Bargerveen, could cause more local precipitation and a cooling effect during heatwaves.

Lastly, due to their moisture retention and cooling effect, wetlands can increase the local resilience to wildfires, as they lower the frequency and severity of wildfires (Kettride et al., 2017). Endter-Wada et al (2020) wrote that the riparian nature of many wetlands helps to reduce the severity or spread of wildfires, especially wetlands with dams, acting as natural firebreaks. This way, animals can find also safety from wildfires. As Bargerveen is an isolated wetland, this is less applicable here. However, it can still mitigate wildfires locally, and the different artificial water structures in Bargerveen, such as pools and canals, could potentially act as firebreaks. Like with the cooling effect in times against heatwaves, this ecosystem service only truly works for restored and well-maintained peatlands, as Kettride et al. (2017) states that drained peatlands are highly susceptible to fires.

Decreasing the frequency and severity of wildfires is an important impact restored wetlands can offer, not only for the direct surrounding, but also globally. Fires in peatlands release large amounts of carbon dioxide, methane and other greenhouse gases, which exacerbates climate change further (Harneda et al., 2018). Thus, fires indirectly affect also the other effects of climate change, as well as wildfires in a positive reinforcement loop.

5.2.3 Compounding hazards

The various hazards can also occur simultaneously or consecutively, without allowing for time to recover from the initial hazard, as explained in the theoretical framework. When this happens, the nature-based solutions that wetlands provide might work differently. The interactions between hazards and their nature-based solutions are shown in Figure 11. The individual relationships between hazard, ecosystem service, and effect are judged individually. Thus, the relationship between drought and wildfire might be positive, as a drought can cause (worse) wildfires, and wildfires can cause a more severe drought, but smaller steps in their relationship might be negative. A negative relationship does not mean that it is bad, for example a worse flood, but purely that if one variable increases, the other decreases. Consequently, a positive relationship does not mean the effect is positive, but that the variables positively enforce each other.

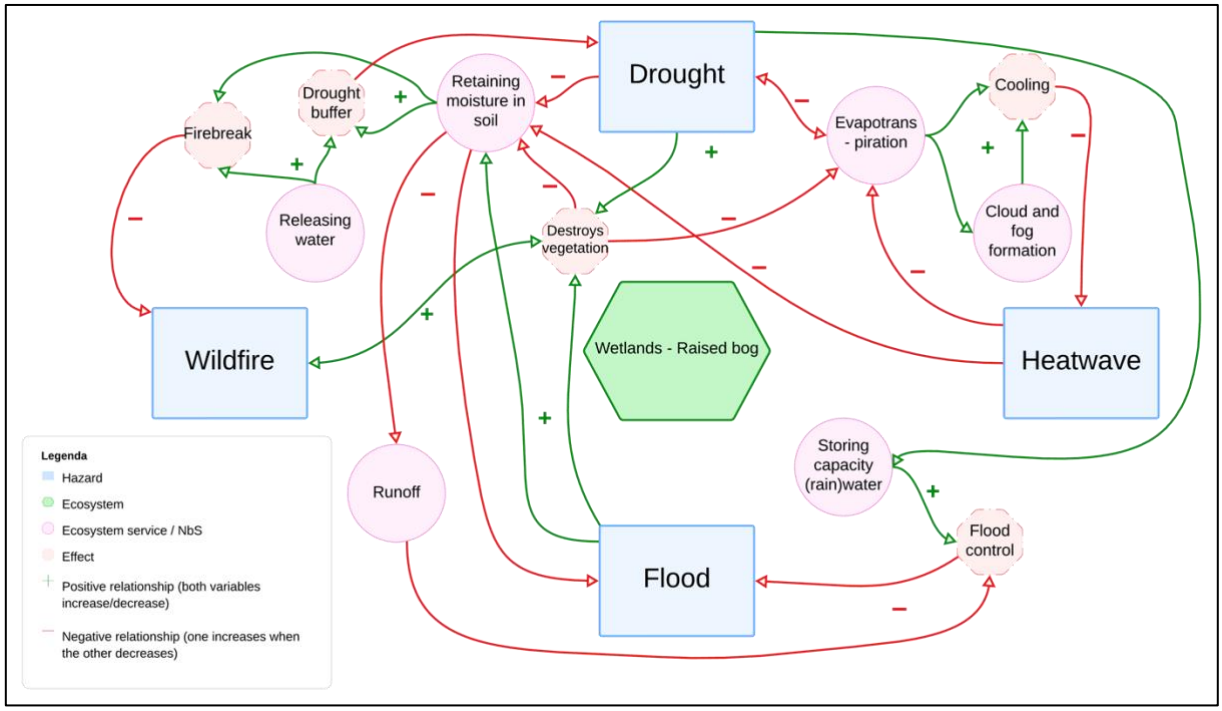

Figure 11. An overview of the various hazards, their NbS, and the interaction with other hazards

The three dry hazards can easily occur at the same time or shortly following each other, as they are dependent hazards. While wetlands could reduce the heat during heatwaves, by their cooling effect of latent heat and cloud coverage, a drought could lessen this capacity. Drought conditions could reduce evapotranspiration, decreasing the latent heat transfer from the ecosystem. Moreover, the reduction in evapotranspiration could decrease the local cloud or fog coverage. Thus, having a drought occur as a compound hazard with a heatwave could decrease the effectiveness of the cooling effect, or the NbS, of the wetland. Simultaneously, heatwave could worsen the drought by affecting the retained moisture in the soil, and surface- or groundwater. This affects the buffering capacity of the wetland to stop a meteorological drought to turn into a hydrological drought.

Droughts can cause the surface- and groundwater levels to decrease, and soil to dry out. This affects the resilience of wetlands against wildfires, as the moisture is key to stop a fire from spreading or developing. Wildfires can damage or diminish the vegetation in the wetland ecosystem. This reduces the evapotranspiration rate the ecosystem has, thus the latent heat transfer and the cloud coverage. Consequently, affecting the cooling effect against heatwaves the ecosystem can give. When the hazards occur as compound hazards, the heatwave can worsen a drought, which can decrease the resilience against wildfires. Wildfires may also harm the vegetation, and affect the evapotranspiration rate, which affects not only the cooling effect,

but could also worsen droughts, as there is less moisture. Thus, the combination of a heatwave, drought, and wildfire can create a vicious cycle where each hazard amplifies the next. The loss of moisture from the drought and fire can not only weaken the wetland's cooling and drought buffering capacity but also increase its vulnerability to future droughts, making it harder to recover.

Wetlands, or raised bogs in particular, are effective at absorbing and storing (rain)water, and this is most effective after longer dry periods, as there is more storage capacity. This means, that a drought can increase the flood resilience of the ecosystem, since the storage capacity is, most likely, larger during or right after a drought. However, a drought can also make the soil that is not covered by the specific type of moss drier. If the soil becomes too dry, it will absorb less moisture, since the water will just discharge. Thus, wetlands can help to reduce the impact of compound drought and flood. When these hazards occur simultaneously, the interplay between the two can create feedback loops that exacerbate or improve the overall impact. Additionally, a wildfire can destroy the vegetation in the wetland, hereby decreasing the wetland's capacity to store water and moisture, leading to decrease in flood resilience. Floods could also damage or kill vegetation, which is critical for the resilience against dry hazards. Therefore, the combination of flood and dry hazards can create a cascade of impacts that weaken the wetland's ability to buffer both types of hazards simultaneously. Yet, a flood also saturates the soil, which can strengthen the drought buffering capacity.

5.3 Optimization of the NbS in Bargerveen

5.3.1 Modelling future groundwater levels

Modelling the future groundwater levels is valuable in evaluating if Bargerveen can function as NbS, since high levels are needed to fully recover the raised bog. The method for modelling the groundwater levels under different scenarios included four main steps. The first step was the correlation test. Two relationships between GW and humidity were not significant, once in set C and once in D. All other relationships are statistically significant. The result of this test on all four datasets can be found in Annex F.

Step 2 was the linear regression test. The R-square values were all statistically significant. Dataset A, C, and D have a slightly higher R-square, than dataset B, indicating that the variation in GW is also explained by another variable that was not included. The full results can be found in Annex F.

Next, the B-coefficients were checked. If they are statistically significant, the variables are included into the equation. If not, the variable is removed and the linear regression performed again. Then, the equation is made. The results are presented in Table 4. In model B, precipitation is not significant, and thus removed, even though the correlation between precipitation and GW was significant. Moreover, since precipitation got such a low B-coefficient (0.001), the difference between running the model with and without precipitation is insignificant. In model C, humidity is kept in, since the p-value is below 0.001. The correlation, however, was not significant. Since, the p-value in this test is low, and the overall R-square high, as well as a normal residual histogram, it is included in the equation. In model D, humidity is deleted since it is not significant, nor was the correlation. This resulted in the following equations (Eq. 2 until 5, see also Table 4).

$$\boldsymbol{GW\ A} = 1583.052 - (0.015 * T) + (0.013 * P) + (0.214 * H) - (1.773 * SW) \quad (2)$$

$$\boldsymbol{GW\ B} = 2067.238 + (0.052 * T) + (0.526 * H) - (3.955 * SW) \quad (3)$$

$$\boldsymbol{GW\ C} = 2020.322 + (0.043 * T) + (0.014 * P) + (0.234 * H) - (3.766 * SW) \quad (4)$$

$$\boldsymbol{GW\ D} = 1897.495 + (0.014 * T) + (0.031 * P) - (2.687 * SW) \quad (5)$$

Table 4 Results from the linear regression test with groundwater (dependent) and independent variables. Red colour indicates the removed variables.

Groundwater dataset	Independent variable	Unstandardized coefficient B	Significance (p-value)
A	Constant	1583.052	<0.001
	Temperature (T)	-0.015	<0.001
	Precipitation(P)	0.013	0.003
	Humidity (H)	0.214	<0.001
	Surface water level (SW)	-1.773	<0.001
B	Constant	2067.238	<0.001
	Temperature (T)	0.052	<0.001
	Precipitation(P)	-0.001	0.913
	Humidity (H)	0.526	<0.001
	Surface water level (SW)	-3.955	<0.001
C	Constant	2020.322	<0.001
	Temperature (T)	0.043	<0.001
	Precipitation(P)	0.014	0.025
	Humidity (H)	0.234	<0.001
	Surface water level (SW)	-3.766	<0.001
D	Constant	1897.495	<0.001
	Temperature (T)	0.014	<0.001
	Precipitation(P)	0.031	<0.001
	Humidity (H)	0.004	**0.891**
	Surface water level (SW)	-2.687	<0.001

Step 3 was to validate the model. This was done by looking at the correlation between the predicted and original dataset. In the next scatterplots (Figure 12), the predicted levels can be compared to the actual recorded groundwater levels. Model A, C, and D predict very similar groundwater levels as the recorded ones. Model B is less precise, but still follows the overall trend. Moreover, all correlations had a p-value of <0.001. The correlation value ranged from 0.804 -0.959. Thus, all correlations were strong. The histograms of the residuals were all close to normal. The means of the residuals were -2.71(A), 9.77(B), 1.21(C), and -6.19(D). These should be close to zero, since that indicates there is little difference between the predicted and actual values. Model A and C pass this test more strongly than model B and D.

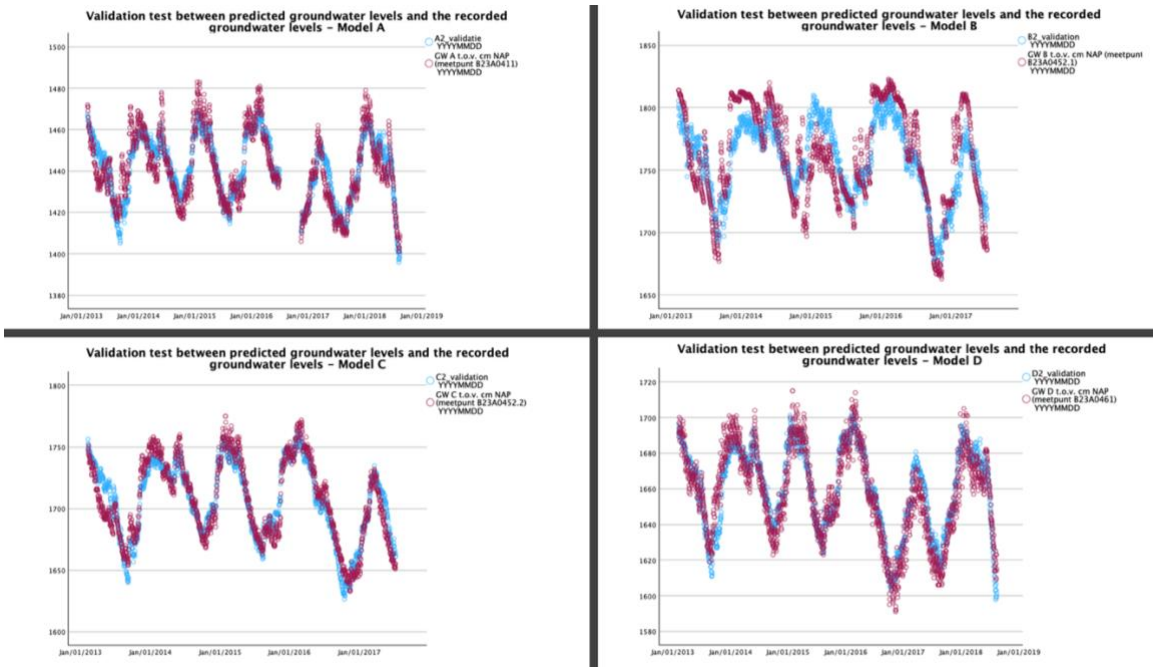

Figure 12. Scatterplots of the predicted vs. recorded groundwater levels in the validation test.

Lastly, the equations are used to predict the GW levels under the different scenarios for 1991-2020. The mean was calculated to show the results in Table 5. The groundwater levels were lower in all prediction, with the biggest decrease in scenario Hn and Hd, which are the high emission scenarios. The prediction of wet or dry climates makes much less of a difference for the water levels than high and low emissions, or high and low temperature. This is understandable when looking at the formulas, since the coefficients for temperature are higher. Temperature has a stronger influence. The surface water levels are the biggest influence on the groundwater level, according to this model, as their coefficient is the highest. However, as surface water levels are predicted by temperature, precipitation, and humidity, these three remain important. The prediction of surface water levels under the four scenarios was done the same way as the groundwater levels, with the correlation, linear regression, and validation step. These results are presented in annex F. The line graphs with trend lines of all predictions are included in annex F. Overall, the line graphs are similar, and the trendline is stable or very slightly decreasing, indicating that the GW lowers over the 30 years.

Table 5 Overview of the means of the various predicted groundwater levels and their respective change.

Location of groundwater data point	**Original mean of GW level (cm)**	**KNMI scenario**	**Mean of predicted GW level (cm)**	**Groundwater level change (cm)**	**Percentage change (%)**
Location A (B23A0411)	1439.77 cm	Hn	1424.53 cm	-15.24 cm	-1.07 %
		Hd	1424.58 cm	-15.19 cm	-1.07 %
		Ln	1431.11 cm	-8.66 cm	-0.61 %
		Ld	1431.17 cm	-8.60 cm	-0.60 %
Location B (B23A0452001)	1757.27 cm	Hn	1729.01 cm	-28.26 cm	-1.63 %
		Hd	1729.27 cm	-28.00 cm	-1.62 %
		Ln	1740.97 cm	-16.30 cm	-0.94 %
		Ld	1740.89 cm	-16.38 cm	-0.94 %
Location C (B23A0452002)	1703.29 cm	Hn	1675.80 cm	-27.49 cm	-1.64 %
		Hd	1676.40 cm	-26.89 cm	-1.60 %
		Ln	1687.82 cm	-15.47 cm	-0.92 %
		Ld	1687.80 cm	-15.45 cm	-0.92 %
Location D (B23A0461)	1659.01 cm	Hn	1635.16 cm	-23.85 cm	-1.46 %
		Hd	1635.77 cm	-23.24 cm	-1.41 %
		Ln	1644.55 cm	-14.46 cm	-0.88 %
		Ld	1644.56 cm	-14.45 cm	-0.88 %

5.3.2 How to optimize the nature-based solutions in Bargerveen

The Bargerveen raised bog faces some unique challenges that might hinder the optimization of the nature-based solutions. As identified in chapter 5.1.1, the reserve's success in recovery and conservation heavily depends on stabilizing groundwater levels, introducing and maintaining appropriate moss species, and, in turn, reducing nitrogen deposition. Hence, the success in mitigating climate change-induced hazards depends on the same factors.

Hydrological and ecological considerations

An important requirement for optimizing nature-based solutions in Bargerveen is stabilizing groundwater levels, which are fundamental to the recovery and functionality of raised bogs ecosystems. High groundwater levels support *sphagnum* mosses, which are key in these ecosystems, and help prevent the invasion of shrubs and trees that undermine resilience and prohibit the NbS functioning for heatwaves. Current management strategies, such as covering exposed peat with hay to maintain a healthy moisture balance in both droughts and floods, are promising to help this issue (Tomassen et al., 2022). Additionally, rising temperatures can accelerate water loss, making proactive water retention measures more critical.

However, Heijmans et al. (2013) concluded that under the current climate, peat bog vegetation is relatively resilient to drought events. It is, however, very sensitive to an increase

in temperature. Hence, under the different future scenarios, that all indicate some level of warming, vegetation can shift. This could impact the mitigating effects the wetlands have, as the cooling and drought resistant affects rely on high evapotranspiration rates and no shrub coverage.

Furthermore, since Bargerveen is situated higher than the surrounding areas, it is still losing water. On most sides of Bargerveen, buffer zones have been, and are being, constructed to limit this water loss. Future projections of groundwater levels in Bargerveen indicate that groundwater levels could decrease by more than 28 cm, under high-emission scenarios. This exacerbated the existing fluctuations that the groundwater has in Bargerveen, namely a change of up to 30 cm annually (Provincie Drenthe, 2023). The successfulness of the recovery of Bargerveen can be hindered by this, as a raised bog, or wetland, can only successfully function as a NbS when healthy and restored.

Managing Bargerveen's NbS is further complicated by the interactions between multiple hazards and their feedback loops, as illustrated in Figure 11 in the previous chapter. Addressing these complexities might require a clear prioritization of hazards based on ecological and societal needs, along with management practices that can respond to shifting conditions.

Strategies for optimization

One opportunity for improving the resilience of Bargerveen lies in fostering cross-border collaboration with Germany. As mentioned before, the eastern boundary is the only side that has no buffer zones, which harms the effort to stabilize the groundwater levels. Addressing this issue through a joint project, potentially with the use of EU or international legislation, could enhance water retention in the raised bog.

Likewise, Strack et al. (2022) indicates that for effective management of peatland and its NbS, multi-stakeholder collaboration is required. Moreover, the involvement of local communities is critical as they state, "Since many people are living in and around peatlands, particularly in temperate and tropical regions, it is indispensable for local people to participate in the activities at all stages" (Strack et al., 2022, p. 78). This is emphasized by the survey results of the next chapter, which show that over 80% of respondents believe it is important or very important for the local community to be included in decisions about development surrounding Bargerveen.

As noted by a study on the use of nature-based solutions for urban adaptation, priority must also be given to increasing social resilience and institutional capacity (Castelo et al., 2023). A lack in capacity is mainly important in developing nations, but is should still be emphasized here. Examples of achieving more social resilience and institutional capacity could be more inclusive decision-making, public-private partnerships, institutional coordination and collaboration, and improving communication and information sharing.

Beyond governance, specific restoration and management strategies can enhance the effectiveness of nature-based solutions. Wu et al. (2023c) conducted a study on the impact of future climate change on flood and drought risk, and how wetlands can mitigate these risks. They concluded that, even though wetlands have mitigating effects on droughts and floods, the combined hydrological regulation of wetlands cannot fully offset the increases risk on flood and droughts due to climate change. They advise two strategies for improving resilience, namely more/improved wetland restoration and using more accurate forecasting.

Motivating wetland conservation and restoration

Evidently, an intact and healthy wetland is vital for the mitigating effects of extreme weather to be successful. In the Netherlands, there is already a great motivation to restore and conserve wetlands, as highlighted by the efforts in Bargerveen. In Germany, however, this motivation seems to be lower. Cultural studies on wetlands have some understanding on increasing motivation and support for conservation and restoration of ecosystems.

Verschuuren (2013) wrote, in a paper on the spiritual services of wetlands, that it would be wise to recognise wetlands spiritual services and religious aspects in management practices, as it can motivate communities to preserve the ecosystems. Wood et al. (2024) performed a systemic review of the cultural ecosystem services (CES) that wetlands provide. Some of these key CES complement hazard mitigations, by indirectly supporting investments in the conservation and restoration of wetlands. For example, increased recreational use, such as biking lanes, often leads to greater public appreciation of wetlands. Likewise, they state that an improved understanding in CES can work as a "powerful motivation for the creation, restoration and improved management of wetlands" (Wood et al., 2024, p. 14). Some studies even estimate the annual value of ecosystem services provided by wetlands to be 47.4 trillion globally (Wood et al., 2024; Davidson et al. 2019). Additionally, to have long-term success in peatland conservation, an important part is to pay attention to place meanings and perceptions from the (local) public (Paulissen et al., 2022). Involving residents in the management of bogs strengthens the support for conservation initiatives (Paulissen, 2023).

In summary, optimizing nature-based solutions in Bargerveen requires an integrated approach that stabilizes hydrological conditions, adapts to ecological vulnerabilities, and leverages social and cultural motivations. Addressing these challenges not only strengthens the capacity to mitigate compounding hazards but also ensures the long-term sustainability of its ecosystem services. This underscores the critical interplay between ecological management, cross-border governance, and public engagement in optimizing nature-based solutions under climate pressures.

5.4 Informing disaster risk management

The European Union and other international legislation are discussed first, since some national policies are based on these regulations. In Figure 13, a flowchart of all policies can be seen. This flowchart provides a visual overview of the key policies impacting the management of Bargerveen. Moreover, it illustrates the different layers of governance and how the different levels interact.

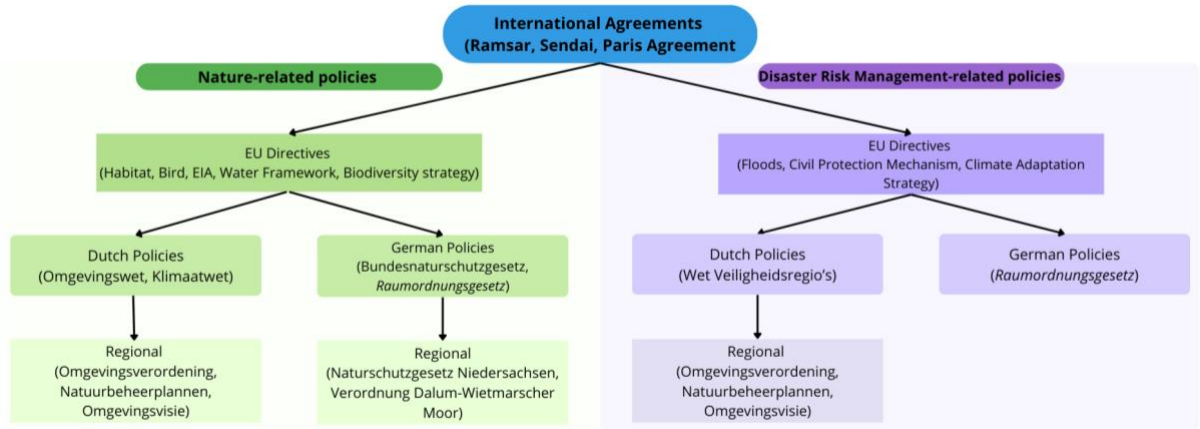

Figure 13. Flowchart of the different policies discussed in the policy evaluation.

5.4.1 EU and International legislation and regulation

The Habitat directive (92/43/EEC), together with the Bird directive (2009/147/EC), form the basis for Nature 2000 regulation. Together, they have created the Nature 2000 network, which is the largest network of protected areas in the world (EEA, 2023). The Dutch part of Bargerveen is a Nature 2000 protected area. For unknown reasons, most of the German side of the wetland is not, and, thus, does not fall under these two directives, with the exception of a very small area called Dalum-Wietmarscher moor, which falls under the Bird directive.

EU Habitat directive

The aim of the directive is to protect special plants and habitat types and to ensure biodiversity through conservation and restoration of natural habitats of wild fauna and flora (Council Directive 92/43/EEC, 1992, art. 2). Moreover, measures need to consider the economic, social, and cultural requirements and local characteristics (art. 2.3). Thus, measures affecting Bargerveen should aim to maintain and restore the natural wetland and should consider the local requirements. For example, include locals in discussion on Bargerveen. This is being done in the Netherlands, as residents are actively included in the management of Bargerveen (Klaas van den Berg (Staatsbosbeheer), personal communication, October 25, 2024; Piet Ursem (Staatsbosbeheer), personal communication, October 31, 2024)

All EU member states need to take appropriate steps to avoid the deterioration of the assigned habitats and the species in it, as article 6.2 states. Furthermore, any plans or project that could affect the sites needs to have an appropriate assessment done to consider its implications on the conservation objectives (6.3). This means that any plans in the Netherlands, but also in Germany, since they are also a member state, needs to consider their effects on Bargerveen. If the effect is assessed to be negative, compensatory measures to protect overall Nature 2000 are then needed (6.4). Both rangers (*boswachters*) from Staatsbosbeheer mentioned and confirmed that the German farmlands on the east of Bargerveen have constructed an extra pump to remove excess water away from their land as they prefer dry lands for farming (Klaas van den Berg (Staatsbosbeheer), personal communication, October 25, 2024; Piet Ursem (Staatsbosbeheer), personal communication, October 31, 2024).

Moreover article 12 states that MSs, so both the Netherlands and Germany, need to take action to prohibit the “deterioration or destruction of breeding sites or resting places”, which Bargerveen is.

EU Bird directive

The Bird directive was adopted in 1979 and is currently recognized as one of the first environmental legislation pieces to be adopted by the EU. It was amended in 2009, hence now being referred to as Directive 2009/147/EC. The directive requires all MSs to protect wild bird species and to restore their habitats (Directive 2009/147/EC, 2009). Article 1 specifies that all MSs are responsible for all naturally occurring birds and their habitats in European territory, and, thus, Germany is also responsible for Dutch habitats such as Bargerveen. Article 3.1 states MSs need to take requisite measures to preserve, maintain, or re-establish a diversity of habitats. Additionally, article 3.2 mentions certain measures should be taken to establish these habitats, such as the “upkeep and management in accordance with the ecological needs of habitats inside and outside the protected zones” (article 3.2.b). Article 4 echoes this sentiment, stating that "outside of the protected areas, member states shall also strive to avoid pollution or deterioration of habitats." Accordingly, if the ecological integrity of Bargerveen is affected by activities or management practices in surrounding areas (including those in Germany), then there is an obligation to take action to protect and preserve its ecological needs. Hence, transboundary cooperation between the Netherlands and Germany is needed, according to both Nature 2000 regulations.

EU Environmental Impact Assessment (EIA) directive

The EIA Directive (2011/92/EU) declares that an EIA is required for all plans and project that can have a significant impact or effect on the environment (art. 1 & 2). Exactly when an EIA is needed, determined in article 4, specifically, there are obligatory examples and situations where the MSs decide, one either through a case-by-case examination or by set thresholds and criteria. The general public needs to be informed and included in an EIA (art. 6). Likewise, other affected countries should be notified timely, according to article 7, to consult on the EIA, ensuring that all concerns raised by the affected state (the Netherlands, or Bargerveen), are thoroughly considered.

Ramsar Convention

Bargerveen is recognized as a wetland of international importance under the Ramsar Convention, an international treaty for the conservation and sustainable use of wetlands (Ramsar Convention, n.d.). The convention obligates the Netherlands to maintain the ecological character of designed sites. It was adopted in 1971, in the city of Ramsar and came into force in 1975. Article 3 of the convention emphasizes the need for all parties to ensure the maintenance of the ecological character of wetlands (Ramsar Convention on Wetlands, 1971). Article 5 calls for an exchange of information and cooperation related to wetlands where water systems are shared between parties. Moreover, they need to coordinate and support present and future policies and regulations concerning the conservation of wetlands. Both Germany and the Netherlands are parties under the convention, thus, they are encouraged to cooperate to conserve transboundary wetlands. This is also one of the three pillars of the convention, cooperation on transboundary wetlands (Ramsar Convention, n.d.). Even though the German side of the wetland does not fall under the Ramsar Convention.

Sendai Framework for Disaster Risk Reduction

Lastly, the *Sendai Framework for Disaster Risk Reduction 2015-2030* is valuable in this context. It emphasizes investing and increasing resilience in disaster risk management, and enhancing disaster preparedness (UNDRR, n.d.-b). By using wetlands as a NBS to reduce the impacts of the consequences of climate change, such as floods, the resilience is strengthened. The framework specifically promotes the use of ecosystem-based approaches to increase resilience in paragraph 28(d) (United Nations, 2015, -b). Besides, the same paragraph encourages transboundary cooperation to grow resilience and reduce disaster risk.

EU Civil Protection Mechanism (CPM)

The CPM aims to strengthen cooperation and coordination between the EU and member states to improve disaster response to natural and man-made crises (Regulation (EU) 2021/836, 2021). The European Commission set five goals to improve disaster risk management, three of which are important to note. The first goal is "to improve risk assessment, anticipation, and disaster risk management planning" (European Commission, n.d. -b). Bargerveen could be included in DRM planning, for example in the DRM assessment and planning by Veiligheidsregio Drenthe. The second goal is "to increase awareness and preparedness of the population to reduce the impact of disasters" (EC, n.d. -b). By including the (local) population in decisions surrounding Bargerveen and its capacity for DRM, you increase their preparedness. The last goal is to increase the response capacity of the CPM (EC, n.d. -b). Bargerveen's potential for climate adaptation could play a role in addressing critical gaps during disasters. Integrating Bargerveen into the response strategy of the CPM, or more regional like Veiligheidsregio Drenthe, could serve as an adaptive measure to reduce the impacts of disasters. The CPM also promotes cross-border and transnational cooperation.

EU Floods Directive

Directive 2007/60/EC, known as the EU Floods Directive, aims to assess and manage flood risk in order to reduce the impacts of flooding on the EU member states. Article 4 of this directive mandates that all member states conduct a flood risk assessment. According to the Dutch flood risk assessment by the Ministry of Infrastructure and Water Management (Rijkswaterstaat), the region surrounding Bargerveen is not at risk for flooding, since it is on high ground (Slomp, 2012). Even though, the Bargerveen region is situated in two river basins, namely the Eems and the Rhine (Slomp, 2012). Article 7.3 highlights the importance of incorporating natural floodplains and areas with the potential to retain floodwaters into flood risk management plans. These plans may also promote sustainable land use practices, improve water retention, and allow for the controlled flooding of certain areas during flood events. Such

measures would work well in Bargerveen, as it can function as a flood buffer. Lastly, article 8 highlights the importance of collaboration in managing flood risk for shared river basins between MS.

EU Water Framework Directive

In 1995, the European Commission adopted a communication to the Parliament and the Council on the use of wetlands and its ability to protect water resources (Directive 2000/60/EC, 2000). The Water Framework directive aims to protect and improve the quality of water bodies Moreover, in article 1e from the water framework directive (Directive 2000/60/EC) states that it protects types of water bodies that contribute to mitigating the impacts of floods and droughts. Bargerveen could be considered such a water body, as it is permanently flooded and can contribute to mitigating the impacts of both floods and droughts. If the Netherlands were to include Bargerveen in its management plans for water bodies under this directive, Bargerveen would have to be maintained and restored to a good ecological status, in line with the directive's objectives. Moreover, its function in flood and drought mitigation would need to be properly recognized and integrated into national water management strategies.

EU Biodiversity Strategy for 2030

The communication on the biodiversity strategy of the EU highlights the importance of protecting (potentially) carbon-rich ecosystems, such as wetlands (EC, 2020). They state, "Nature regulates the climate, and nature-based solutions, such as protecting and restoring wetlands, …, will be essential for emission reduction and climate adaptation." Furthermore, investments in floodplain restoration, for example wetlands, can improve flood protection.

EU Strategy on Adaptation to Climate Change

The climate adaptation strategy sets out how the EU can adapt to the effects of climate change and how to become more climate resilient by 2050 (EC, 2021). The strategy has multiple principal objectives. In the context of this study, two are relevant. The first objective is to adapt faster and more comprehensively. The strategy aims develop adaptation solutions that can reduce climate-related risk, such as floods, droughts, wildfires, and heatwaves. Since Bargerveen is already actively being restored and conserved, it could relatively swiftly be used as an adaptation solution. The German side of the raised bog would need more help and time. The second relevant objective is to make climate adaptation more systemic and to implement adaptation strategies at all levels of governance with nature-based solutions and local adaptation action as a priority. The use of Bargerveen for climate adaptation would need a systemic approach with multiple levels of governance, as Staatsbosbeheer, the municipality, the province, and the national government of the Netherlands, and potentially Germany, would be included.

United Nations Framework Convention on Climate Change 2015, Paris Agreement

The Paris agreement is also relevant for climate adaptation for disaster risk management in Bargerveen. Article 2 states that the aim of the agreement if to increase "the ability to adapt to the adverse impacts of climate change…" (UN, 2015a). Bargerveen could mitigate adverse climate impacts, contributing to the agreement's overarching goal. Article 6 provides flexibility for member states to pursue ambitious mitigation and adaptation strategies, which allows for innovative cross-border initiatives that Bargerveen could pose. Article 7 further underscores the global goal of enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change. This aligns with efforts to restore the raised bog, which can enhance the area's capacity to buffer extreme weather events. Additionally, article 7.6 and 7.7e highlight the need for international cooperation and durable adaptation actions.

5.4.2 Dutch legislation and regulations

Environmental and Planning Act (Omgevingswet)

The *Omgevingswet (2024)* is a comprehensive law that has incorporated 26 pre-existing laws and regulations. Laws that were incorporated into this law are, for example, Nature Conservation Act (*Natuurbeschermingswet*), Water Act (*Waterwet*), Soil Protection Act (*Wet bodembescherming*), and the Crisis and Recovery Act (*Crisis- en herstelwet*). This law went into force on January 1st, 2024, and regulates spatial planning, infrastructure, housing, the environmental, nature, and water (IPLO, n.d.).

The act is concerned with, according to article 1.2, the physical environment and activities that affect or may affect the physical environment. It aims to "effectively manage, use and develop the physical environment to fulfil societal needs" (art 1.3, b). Bargerveen could be developed, used, and managed to fulfil the need for climate adaptation and disaster risk management, making it a valuable NbS. The duties and powers of administrative bodies must align with the objectives of the *Omgevingswet* (art 2.1). For Bargerveen, thus could entail addressing its role in mitigating climate change and its impacts (art 2.1, sub 3i), managing its ecosystems and water systems (art 2.1, sub 3n & 3o), and protecting its status as a nature conservation area (art 2.1, sub 3q). Administrative bodies must also consider the interrelationship between different components of the physical environment and the societal interest directly involved (art 2.1, 2).

Under the *Omgevingswet*, water management is governed by provisions from the former *Waterwet*. Hydrological restoration projects in Bargerveen, such as adjusting water levels to conserve the raised bog, would need to comply with the objectives stated in the act. Moreover, collaboration with, for example, regional water boards is needed, as article 2.2 states that administrative bodies must work together in managing the physical environment. Additionally, any activities with significant environmental impact, such as infrastructure construction or changes to water systems, would require permits in accordance with article 5.1.

If an activity is likely to harm the integrity of a Natura 2000 site, it needs to undergo an appropriate assessment (art 5.1). This ensures compliance with both national and EU directive, such as the Bird, Habitat, and EIA directive, and safeguards the ecological and hydrological integrity of these protected areas. The *Omgevingswet* simplified the procedures for such assessments.

Safety Regions Act (Wet veiligheidsregio's)

The Netherlands is divided into 25 safety regions, where the mayors of the included municipalities form the crisis management team, called *Veiligheidsregio Drenthe* (VRD) (2024, art 8 and 9). The province of Drenthe forms one large safety region, in which Bargerveen falls under. The crisis management team is in charge when a crisis or disaster occurs or deems to occur.

Every four years, each safety region must make a management plan (art 14) based on their risk profile (art 15), the latest version of both is from 2024. The risk profile is called *Regionaal Risicoprofiel 2025*, and the management plan is called *Beleidsvisie 2025-2028* (VRD, 2024-a & VRD, 2024-b). The risk profile describes, among many other types of crises, the danger of a changing climate, like heatwaves, water scarcity, flood risk, and wildfire risk. They specifically mention the danger of droughts and wildfires for Bargerveen. Moreover, they highlight that a drought in raised bog can cause water scarcity, dikes that dry out and collapse, and consequently floods.

The risk profile presents a risk matrix that shows how serious and how probable the risk is to Drenthe. Wildfires are described as serious and very probable, while extreme weather is very serious and probable. Droughts, floods, and heatwaves are not explicitly mentioned in the matrix, but they could potentially be seen as consequences from extreme weather. Worryingly, they state that more extreme weather events will occur and that there will be big impacts for Drenthe, but that is it unclear how to best prepare for them. In a different section of the risk

profile, they do state that they get at a code red warning at least an hour before the event that is very precise on where the impacts will be worst. For floods, they will also get a warning ahead of time so they can prepare. For wildfires, they mostly discuss preventative measures by telling people what to expect and what to do, thus increasing self-reliance. They do not state other preventative measures, such as arranging nature in a way that the spread of fire is stopped. The risk profile does indicate that more preventative measures will be taken under the *Omgevingswet.*

The management plan mostly discusses how the crisis management team is prepared for risks and disasters, so Bargerveen is not mentioned in the management plan. Neither are risk reducing solutions, as it mainly states who does what when a crisis occurs. The focus of the plan is on self-reliance. Interestingly, the management plan, or *Beleidsvisie*, of 2020-2023 does mention some of these points. This plan starts with five main focal points, such as preparing for unknown crises, and making sure the fire department is prepared for the future. Another important point, although not one of the main five focal points, is attention for climate adaptation.

According to article 16 of the safety act, all regions also must present a crisis plan every four years. The main theme of the crisis plan is, again, self-reliance. This plan is truly a document of who does what when different disasters occur. For example, when they consult the entire management team and when there is too little time to do that.

Climate act (Klimaatwet)

The climate act (2023) describes the aim to reduce the net greenhouse gas emission to zero by 2050, and to negative numbers afterwards. The climate plan for the next 10 years (2021-2030) includes an overview of the most recent academic insights into reducing climate change, and an overview of the most recent European and international developments surrounding climate change (art 3.2). The climate plan mainly focusses on the energy sector and transition, and they mention peat to store excess carbon. Moreover, they discuss costs of the climate crisis at length, probably since the ministry of climate is also the ministry of economic affairs (Ministerie van Economische Zaken en Klimaat, 2020). The climate act and climate plan seem to be focused on reducing climate change, and not reducing the *impacts* of climate change, as there is little to no attention to climate adaptation.

Provincial environmental regulation Drenthe (Provinciale omgevingsverordening Drenthe)

According to the provincial environmental regulation, Drenthe states that developments should demonstrate how they support multifunctional land use (Provincie Drenthe, n.d., art 3.17a). For example, integrating benefits like climate adaptation and biodiversity conservation or carbon uptake. Thus, combining the use of Bargerveen as NbS with another function would be ideal. Moreover, it underlines the importance of having spatial, social, and landscape value when planning transformations (art. 3.22). For Bargerveen, this could entail that next to its use as NbS, it must also support biodiversity or enhance recreational use. Project could be supported by financial mechanisms, when keeping this multiuse and multi-value in mind.

The regulation also includes a nature network map of Drenthe (*Natuurnetwork Nederland (NNN)).* This map shows all nature areas in the Netherlands and their connections. The published map of 2020, 2022, and 2024 of Drenthe were found. All maps show Bargerveen as also illustrated in the various maps of chapter 5.1. However, the map of 2020 and 2022 show an ecological connection from Bargerveen over German land. The connection appears as green, which means that it is in function. The map of 2024 does not show this ecological connection, not in green or in red. According to the province, this connection was not intentionally removed (personal communication, January 20, 2025). They state that this is most likely due to another map overlying, which caused it to disappear. Since the connection is outside of the province, they do not have much power over if they connection is created. They state that, if the connection does not exist fully, that it is their wish to create one.

Nature management plans Drenthe (Natuurbeheerplannen)

The plans were discussed in more detailed in chapter 5.1. Some important points are that these plans state that climate adaptation can include holding more water in infiltration areas (Provincie Drenthe, 2024). Moreover, climate services, or ecosystem services should be clustered and deployed in a demarcated area. These climate services cannot be deployed in land type N00.01, which is yet to be transformed into nature. In Bargerveen, this land type does occur, but only very minor pieces of it. A request to use these climate services will be handled by both the province and the water board. If the services are already being used and it is successful, they should continue. Lastly, they state that climate adaptation is being pursued through means of rewetting, capturing water peaks and droughts, and addressing salinization.

Environmental and Planning Drenthe (Omgevingsvisie Drenthe)

This policy document is written in accordance with the national *Omgevingswet*. This document highlights the importance of creating an environment that can adapt to the changing climate, both the gradual temperature increases and the weather extremes (Provincie Drenthe, 2022). A robust water system is crucial to achieve this, according to the document. They strive towards optimal use of water systems and soil to mitigate the effects of climate change. They also reiterate the use of multifunctional spaces, where they combine the cities, agriculture, nature, and water. Moreover, the soil is full of solutions and chances for climate adaptation and climate mitigation. They, most likely, refer to capturing water and carbon.

5.4.3 German legislation and regulations

Federal Nature Conservation Act (Bundesnaturschutzgesetz (BNatSchG))

The nature conservation act is the overarching law for nature conservation in Germany, which includes the EU Bird and Habitat directive (BMUV, 2009). The aim of the act is to protect nature and landscapes, safeguard biodiversity, safeguard a natural balance, protect areas against further fragmentation, and protect open spaces (art 1).

Most of the German part of the raised bog is a designate nature park and protected as such. That alone does not protect the nature per se. Nature parks are developed and managed the same and are intended for recreational purposes (art 27.1). They are also “particularly well-suited to the promotion of sustainable regional development” (art 27.1 sub 6). The parks should be planned and developed with regard to nature conservation and landscape management. There are, however, no legal restrictions set specifically for nature parks. Only nature conservation areas are protected legally for, for example conservation, restoration, science, or rare species (article 23.1). The areas are of high ecological value. In these zones, all actions that could lead to damage or changes in the area are banned (art 23.2). The NSG can be opened to the public, but only if this does not harm the protection purposes (art. 23.2). The red covered land in Figure 8 in chapter 5.1 are nature conservation areas (NSG). None of these areas directly border Bargerveen, but some are situated in the nature park that does border Bargerveen. The biggest NSG zone in this park is called Dalum-Wietmarscher Moor and has its own regulation (*verordnung*), which will be discussed further in its own section.

Landscape protection areas (LSG) are areas in which protection of nature and landscape is required for a many different reasons, such as conservation, develop or restore a proper functioning natural balance (art 26.1). All actions that could alter the character of the area or interrupt the purpose of the protection are prohibited in the area (art 26.2). This is less strict than for NSG. In Figure 8 in chapter 5.1, the green covered land are landscape protection areas. They do not border Bargerveen or are very close to it.

Lower Saxony Nature Conservation Act (Naturschutzgesetz (NNatSchG))

The German state that borders Bargerveen, called Lower Saxony, has its own translation of the federal nature conservation act. This act specifies that NSG cannot be entered outside of

the designated paths, except if the purpose of the protection requires or allows it (art 16). They do not have any specific remarks on LSG.

Regulation Dalum-Wietmarscher Moor (Verordnung)

This regulation is on the NSG in the south-east of the nature park that borders Bargerveen. According to article 2, the purpose of the NSG is to preserve, manage, and develop the peatland and adjacent grasslands. One objective is to promote raised bog regeneration, where they use rewetting (art 2.3). This NSG falls under the Natura 2000, due to the bird directive. The protection of birds and its habitat is a prominent theme in the regulation. In article 6 the management measures are described. They include rewetting previously harvested peatlands to promote bog regeneration, removing invasive vegetation to restore raised bog and, implementing conservation measures. Apart from rewetting, it does not describe other management types to promote bog regeneration, such as moss introduction or ways to maintain groundwater levels.

Federal Spatial Planning Act (Raumordnungsgsetz (ROG))

The spatial planning act ensures that the entire territory of Germany is planned, organized, and protected through comprehensive regional plans that integrate and coordinate important regional project and measures (art 1.1). The goal is sustainable (regional) development that balances social and economic demands with ecological functions, creating a stable and well-balances system (art 1.2). Regional planning is governed by certain principles that are defined in article 2.2. For instance, open spaces shall be maintained and improved where productive land use, the water balance, flora and fauna, and the climate can function together (sub 3). Moreover, adverse environmental effects shall be reduced (sub 5), and groundwater resources shall be protected (sub 8). Subsection 8 of article 2.2 further states that provisions shall be made for preventative flood protection, which in-land will be protecting and restoring meadows, retention areas and areas that are flood-prone. These principles of objectives shall be observed by public authorities (art 4.1). Lastly, article 16 states “Regionally significant plans and measures that may have substantial impact on neighbouring countries shall be coordinated with the neighbouring countries affected in accordance with the principles of reciprocity and equivalence.” Thus, any plans close to the border with Bargerveen that can have a substantial impact on Bargerveen, need to be coordinated with the Netherlands.

5.5 Perspective of the local community on Bargerveen

5.5.1 Descriptive results

The survey got 60 useable responses. This is eight responses fewer than the minimum required responses to be able to say that the survey is representative, as this number was 68-105 responses depending on the margin of error. Most people who completed the survey, did so in response to the article in the newsletter of Bargerveen-Schoonebeek. The respondents live in 19 different places surrounding Bargerveen. The village of Klazienaveen is represented the most, with 16.7% of people living there. Zwartemeer and Nieuw-Schoonebeek are tied close second with 13.3%. Three quarters of respondents have lived near Bargerveen for over 10 years. Most people visit Bargerveen weekly or a few times per week (58.3%), with only 3.3% of responses stating they never visit Bargerveen.

When asked what the impact of Bargerveen is, most people filled in that their lives have been (very) positively impacted, with 65%. Only 6.7%, or four people, stated that their lives have been negatively impacted by the changed to Bargerveen. When asked in a later question what disadvantages they think Bargerveen poses to the local community, three out of the four people responded with concerns for loss of agricultural land and income. Another disadvantage according to two of the four people is the increased chance of water nuisance and flooding.

While most respondents indicated a positive impact from the changes to Bargerveen, opinions on its overall advantages and disadvantages for the local community were more varied.

A small portion (5%) believed that Bargerveen offers no benefits at all to the local community. In contrast, a larger group (38.3%) stated that they see no disadvantages associated with Bargerveen. When looking toward the future, 56.7% of respondents reported having no concerns about future developments in Bargerveen. Only 6.7% expressed that they hold no positive expectations for Bargerveen's future, thus, indicating a generally positive or neutral outlook.

The overall perception of current state of Bargerveen in terms of biodiversity and water management is largely positive (78.3%). Only 5% of people perceive the current state as negative. Notably, no one rated the state as very negative. When asked about the potential role the nature reserve could have in mitigating extreme weather, opinions are more divided. About 42% believe that Bargerveen could help mitigate the impacts, 35% remain neutral, and 23.3% think that it cannot contribute to climate adaptation. This indicates a level of uncertainty or scepticism among a portion of the local community regarding Bargerveen's function in climate adaptation.

Despite this, there is strong support for adapting Bargerveen's policies to climate change. A large majority of respondents consider such adaptations to be important or very important (80%), while only 6.7% of people think that is not (at all) important. In a follow up telephone call, two people explained voting that this is not at all important. Person A reasoned that climate change will not impact Bargerveen much, while also indicating that their village has already changed enough over the years. This change was mainly due to farmers moving away. Likewise, person B stated that agriculture has already suffered enough in the region, so 'enough is enough'. Their concern was mainly on the change in groundwater levels, as they affect the agricultural fields and surrounding villages. The agricultural fields and villages should remain dry, but it is unclear how this will be achieved.

There is also significant support for including the local community in decision-making surrounding Bargerveen, as over 83% of people state that this is (very) important. Four people, or 6.7%, stated that this is not (at all) important. In the remark section of the survey, one of these people (person F) write that they do think it is important to inform the community well and on a timely manner, but that they should not be included directly in decision-making. Moreover, they stated that by informing the people well, you will create more enthusiasm for the projects. Another person that voted that it is not important to include the community, explained their answer in a follow up email (person E). They explained that the community always responds negatively to decisions surrounding Bargerveen, based on their experience on the Facebook page of Bargerveen. For example, it is bad when they mow the grass, but also wrong when they do not mow the grass. Person E, similarly, to person F, thinks the community should be informed but not directly included in decision-making processes.

5.4.2 Correlation analysis

A correlation test was performed between the six closed ended (rated on a scale from 1 to 5) questions. This resulted in 15 pairwise comparisons, as each question (variable) was tested against every other question to identify potential correlations. Only two tests were statistically significant and thus indicated a correlation between the two questions. All correlation results can be found in annex G, while the two significant results are shown below in Table 6. The first significant test was between the questions 'To what extent do you think nature reserves like Bargerveen contribute to mitigating the impacts of extreme weather events (e.g., floods, droughts)?' and 'How do you perceive the current state of the Bargerveen nature reserve in terms of biodiversity and water management?'. The coefficient indicated a moderate positive correlation between these two questions, indicating that respondents who viewed the current state of Bargerveen more favorably were also more likely to believe that it plays a role in mitigating extreme weather impacts. The second significant test was between the question on Bargerveen's ability to mitigate extreme weather and the question 'How important do you find it to develop policies that protect and adapt nature reserves like Bargerveen to changing climate

conditions?'. This correlation was also positive and moderately strong, suggesting that the people who see Bargerveen as effective in mitigating extreme weather, were more likely to support adaptive policies.

Table 6 Results from the correlation tests with the entire dataset of the survey (N=60).

Question topic 1	Question topic 2	Correlation Coefficient (Spearman's Rho)	Significance (p-value)
Bargerveen's contribution to extreme weather mitigation	Perception of current state of Bargerveen	0.433	<0.001
Bargerveen's contribution to extreme weather mitigation	Importance of adapting Bargerveen's policies to a changing climate	0.494	<0.001

During the collection of survey responses, answers appeared to be more consistent when the survey link was shared only through the newsletter compared to when it was also posted on the Facebook page. Therefore, correlation tests were also conducted using only the responses received via the newsletter, which resulted in more correlations. To perform these correlation tests, the dataset was split into answers that came in before the link was posted on the Facebook page (N=47, 'newsletter respondents'), and answers that came in after (N=13). Only the replies from the newsletter were used in the following correlation tests. The full results are included in the annex G.

Restricted to the newsletter respondents, six tests were significant, as shown in Table 7. Notably, the same two tests as before are significant. The four new significant tests are between the question 'How has your live changed due to the developments changes to Bargerveen in the last few years?' and four other questions, namely, 'How often do you visit Bargerveen?', 'How do you perceive the current state of the Bargerveen nature reserve in terms of biodiversity and water management?', 'To what extent do you think nature reserves like Bargerveen contribute to mitigating the impacts of extreme weather events (e.g., floods, droughts)?', and 'How important do you find it to develop policies that protect and adapt nature reserves like Bargerveen to changing climate conditions?'. All correlations are positive and range from weak to moderate in strength. Thus, the more frequently they visit Bargerveen, the more positive the impact of Bargerveen is on their lives. Additionally, the more positive they view the impact of Bargerveen has on their live, the more positive rate the current state of Bargerveen, the more they believe in Bargerveen's ability to mitigate extreme weather, and the more important they view adapting Bargerveen's policies to climate change.

Table 7 Results from the correlation tests with only the data acquired from the newsletter (N=47).

Question topic 1	Question topic 2	Correlation Coefficient (Spearman's Rho)	Significance (p-value)
Impact of Bargerveen on respondents' life	Visitation frequency of Bargerveen	0.350	0.008
Impact of Bargerveen on respondents' life	Perception of current state of Bargerveen	0.503	<0.001
Impact of Bargerveen on respondents' life	Bargerveen's contribution to extreme weather mitigation	0.475	<0.001
Impact of Bargerveen on respondents' life	Importance of adapting Bargerveen's policies to a changing climate	0.272	0.032
Bargerveen's contribution to extreme weather mitigation	Perception of current state of Bargerveen	0.362	0.006
Bargerveen's contribution to extreme weather mitigation	Importance of adapting Bargerveen's policies to a changing climate	0.489	<0.001

5.5.3 Thematic analysis

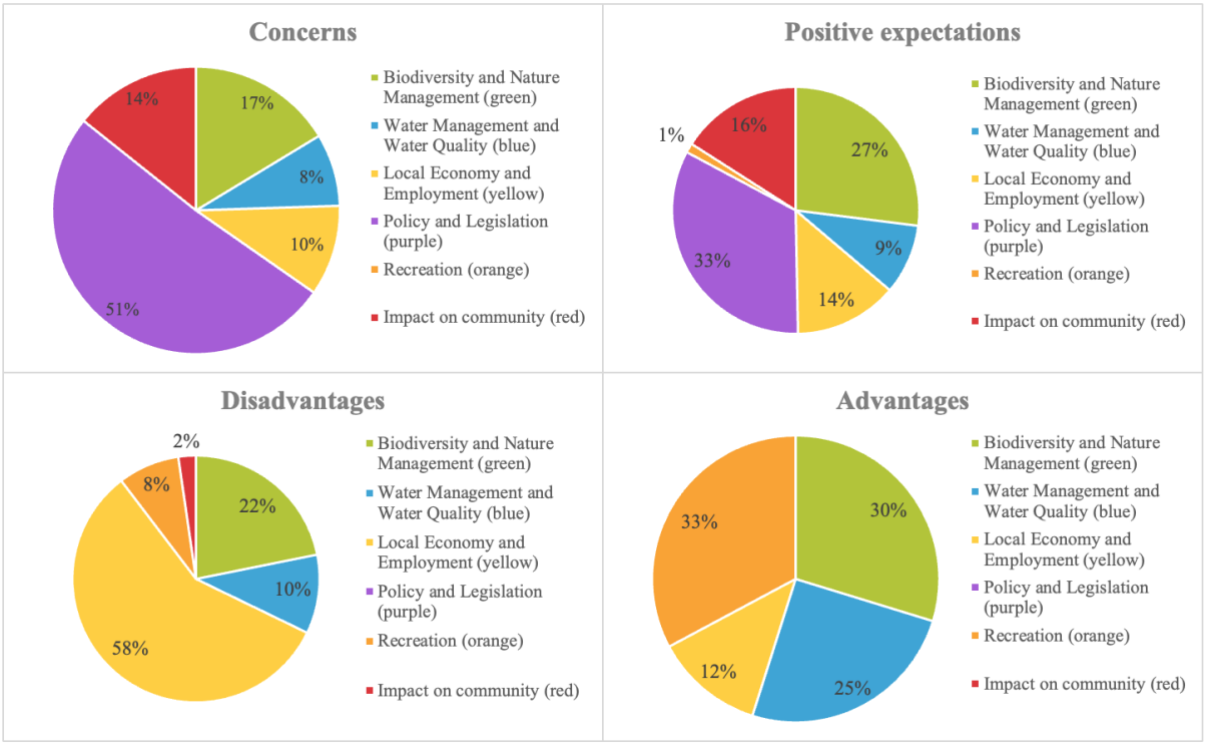

Figure 14. Pie charts of the thematic analysis of the open-ended questions in the survey.

The thematic analysis was performed on the four open ended questions, namely 'What benefits do you think Bargerveen, as a protected nature reserve, currently offers to the local community?', 'What disadvantages do you think Bargerveen, as a protected nature reserve, currently presents for the local community?', 'If any, what are your concerns for the future developments of Bargerveen?', and 'If any, what are your positive expectations regarding future developments in Bargerveen?' The analysis categorized responses into six main themes: (1) *Biodiversity and Nature Management, (2) Water Management and Water Quality, (3) Local Economy and Employment, (4) Policy and Legislation, (5) Recreation, and (6) Community Impact.* Respondents could pick multiple options that were pre-written, while also adding their own. Pre-written answers were given, as the concern was that people would not respond to the questions if it were to be left completely open. Moreover, they could select an option for no response, if they, for example, had no concerns.

Across all categories, benefits (196) were the most frequently mentioned, followed by positive expectations (163) and disadvantages (87). Concerns were noted in 49 responses, while 34 respondents explicitly stated they had no concerns. Similarly, 23 participants saw no disadvantages, and four respondents reported no positive expectations. The results of the thematic analysis can be seen in the pie charts above (Figure 14). The pie charts do not include the option of No response.

Most participants selected only the prompts that were provided, which were not evenly distributed among the six categories. As a result, some categories were over- or underrepresented in the questions. To assess this imbalance, the expected distribution—assuming all prompts had been selected—was compared to the actual response distribution. This comparison helped identify which themes respondents considered most and least important. If themes were underrepresented, they are found less important, while if themes are overrepresented, they are found more important. There were a few things that stood out. For the concerns surrounding the future of Bargerveen, Water management and quality was underrepresented by 6%, whereas policy and legislation was overrepresented by 8%. For positive expectations for the future, both Policy and legislation, and Water management and quality were underrepresented by 10% and 5% respectively, while Biodiversity and nature

management was overrepresented by 13%. In the answers to the local disadvantages felt in the community due to Bargerveen, Water management and quality was underrepresented by 12% and Local Economy and Employment was overrepresented by 14%. Lastly, in the replies to the advantages or benefits due to Bargerveen, Water management and quality was again underrepresented (-5%), together with Local economy and employment with 8%. Recreation was overrepresented in this question.

To conclude, the theme of Water management and quality if consistently undervalued. Under this theme, the following answers were classified: protection against floods, protection against droughts, and concerns about water nuisance. This suggests that this theme might not be a priority for respondents, even though it is a crucial aspect of wetland management. Moreover, respondents associate the future of Bargerveen with the benefits of biodiversity and nature management. They also value the role of Bargerveen in providing recreational opportunities. However, this does not translate into recognizing that Bargerveen might be an economic asset or provide employment. The theme of Local economy and employment is mostly seen as a disadvantage, mostly in the agricultural sector, suggesting that respondents value Bargerveen as something that negatively impacts the local economy. This was also evident from the follow-up interviews with person A and B. Additionally, Policy and legislation is perceived as more of a concern for the future, rather than a positive expectation.

The results and findings of this survey were shared with Rudy Schuring (*Gebiedscoordinator Emmen*), Carolien van de Bles (*Projectleider Bargerveen, Prolander)*, and interested respondents afterwards, on their request.

6. Discussion

6.1 Interpreting the results: answering the research questions

In this section, the findings from the study will be interpreted, while addressing the research questions. The conditions necessary for a healthy bog ecosystem, including groundwater levels and moss types, are discussed first. When the raised bog is successfully recovered, in other words, when groundwater levels are high and an acrotelm layer is formed, then it can most effectively function as a NbS. How the raised bog can function as NbS is examined next. Optimization strategies are explored, followed by the social and economic implications of implementing nature-based solutions in Bargerveen. Finally, the political aspect of making Bargerveen function as a NbS are considered.

6.1.1 Conditions needed for a healthy raised bog in Bargerveen

The nature reserve is between 17-20 m above sea level, which causes water to flow out of the area. For (recovering) raised bog, one of the most important things is to have a high and stable groundwater level, that is level with the peat or sand level (Tomassen et al., 2022). This remains one of the primary obstacles in recovering the raised bog in Bargerveen. In response to research question 1, this study found that one of the main challenges in restoring the raised bog is not water availability but water retention. The research demonstrated that (ground)water is flowing out of the area, which prevents full recovery.

Moreover, the data analysis from research question 1 showed that in the region of Bargerveen the climate is getting drier and warmer. This can also be concluded from the SPI assessment. When comparing these results with the Standardized Precipitation-Evapotranspiration Index (SPEI) from the Netherlands, from the KNMI, one major difference stands out. In SPI-6, the drought in 2018 is classified as severely dry, whereas in SPI-12, this is only classified as moderately dry. In SPEI-6 and SPEI-12, it is classified as extremely dry, indicating a higher severity (KNMI, 2021). This difference could be attributed to the inclusion of temperature (evapotranspiration) in SPEI, which could account for the increased drought intensity. Thus, SPI might understate drought severity in periods with high evapotranspiration rates, like in 2018. Hence, the concerns surrounding the water levels in Bargerveen might become even more pressing in the future as the climate continues to change.

This was also the conclusion from the groundwater prediction that was made for research question 3. This analysis showed that groundwater levels will decrease in all future scenarios, with the biggest decrease for the high emission scenarios (Hn and Hd). The levels decreased with up to 28 cm, which together with the natural water level variation of 30 cm in Bargerveen, means that it will become much harder to have stable, high groundwater levels. The difference between wet and dry scenarios, however, did not show a big difference, suggesting that precipitation is a smaller factor than overall temperature increase (due to the emission levels). This is troubling, as Heijmans et al. (2013) concluded that peat bogs are resilience to droughts, but very sensitive to increasing temperatures. These changes in temperatures can cause vegetation types to shift, which would inhibit the mitigating ability of Bargerveen. There are some current management strategies in Bargerveen already implemented that could help with maintaining a healthy moisture balance in droughts and floods, which is covering the exposed peat with hay (Tomassen et al., 2022). Making Bargerveen most robust to climate change is a priority, according to the province (2023).

Buffer zones have increased the groundwater levels over the years, but not yet kept the water level stable (Provincie Drenthe, 2023). Unfortunately, even when the latest buffer zone (*Bufferzone Zuid*) is finished, the water will still flow out from the east side, i.e. the side on the German border. It is not possible to construct a buffer zone on Dutch soil, as a large strip of raised bog would need to be sacrificed. The most straightforward way to achieve higher groundwater levels, is to decrease the water flowing out of Bargerveen via the east side. In other words, to reduce the outflow of water toward Germany. This can be done in two ways. First,

and most drastically, is to create an additional buffer zone on the east of Bargerveen, on German land. The other way is by making sure the pump that currently drains water is stopped.

Either of these options might be possible with the help of EU and international law, but the pump issue would be the easier and more logical choice. The EU Habitat Directive (92/43/EEC) states in article 6 that any plans or projects that could affect the site, needs to be assessed. This is the same for the EIA directive. If the effect is assessed to be negative, Germany would have to compensate to protect the site. This pump could be argued to be a plan or project, and it could be assessed as having negative effects. The compensation, in best case scenario could be to create a buffer zone. This way, their land could remain drier, while Bargerveen keeps their water levels high. If Germany is unwilling to compensate or perform an assessment, they might violate the directive.

Both Germany and the Netherlands have signed the Ramsar Convention, which commits them to conserving wetlands. The Netherlands could potentially argue that the actions of Germany, like the pump, undermine their shared responsibility to protect Bargerveen. The Ramsar Advisory Mission (RAM) could assist with this, as it is a technical support mechanism that contracting parties can utilize to seek expert advice on addressing threats to wetlands (Gardner et al., 2018). The threats can be from on-site or off-site activities, so they do not have to be in Bargerveen of in the Netherlands (Gardner et al., 2018). The EU Water Framework Directive (2000/60/EC) requires member states to prevent the deterioration of water bodies. If proven that the extraction of water by Germany negatively impacts Bargerveen, the Netherlands could argue that Germany violates this directive. Germany, it its own Federal Spatial Planning Act, also states that any plans that might negatively impact neighbouring countries, need to be coordinated with the affected country.

According to the European Union (n.d.), the European Commission (EC) has the task to enforce EU law. They can send a letter of formal notice when a member state fails to comply. The member state can then provide explanation on which the EC judges the violation again. If they find them in violation still, they can send a reasoned opinion, in which a deadline is set by when the member state must comply with the law. If all fails, the EU can bring the case before the Court of Justice of the European Union.

Other options to ensure that groundwater or moisture levels do not decrease too much, could be by diverting nearby surface water to Bargerveen in dry periods. This is challenging, however, since Bargerveen is situated higher than the surrounding land. Moreover, if a drought threatens to occur, other sectors or people might also need this water. So, this might only be a viable plan if the water is not used or reserved for someone or something else and does not cause problems elsewhere.

The last opportunity to retain more moisture is to introduce sphagnum moss in Bargerveen. These mosses are not yet growing in Bargerveen, and they are unlikely to appear without introduction (Tomassen et al., 2022). This species is not only vital to create acrotelm and to fully recover the raised bog, but it can also maintain a higher moisture content then other species (Campeau & Rochefort, 2000; Waddington et al., 2010). In a study on re-establishing this type of moss in bogs, Smolders et al. (2003) found that introductions of these moss species appeared to be very successful on areas where other types dominated, or on bare substrates. Currently other moss types are dominating in Bargerveen. However, even in hydrologically favourable conditions, this moss type does not grow well under high nitrogen levels, which is an on-going issue for the Netherlands (Tomassen et al., 2022). The disposition of nitrogen in Bargerveen is lessened though, due to the buffer zones. So, just increasing the water levels and keeping them stable, might not be enough to create a successfully recovered raised bog. Only a small section of the raised bog in Germany they only rewet the raised bog, which is, most likely, not enough to grow an acrotelm layer and fully recover.

6.1.2 Functioning of raised bogs as NbS

To address research question 2, raised bogs can function as a NbS for mitigating the impacts of floods, droughts, wildfires, and heatwaves. A wetland can retain water and release it slowly, which decreases the lag time and the peak flow of the flood (Acreman & Holding, 2013). Droughts are mitigated by wetlands by slowing the progression of hydrological droughts, aiding in faster recovery, and reducing both the intensity and duration of these droughts (Wu et al., 2023a; Endter-Wada et al., 2020). Wetlands can also buffer the transition from meteorological to hydrological droughts (Wu et al., 2023a). Heatwaves are mitigated by the high evapotranspiration rates that wetlands have. Wildfires can be mitigated by wetland's firebreaks and high moisture content.

6.1.3 Optimizing Bargerveen as NbS

To optimize the nature-based solutions for Bargerveen, as was the focus of research question 3, the raised bog requires full restoration. This is due to multiple reasons. First, a fully formed acrotelm with the correct moss type (*sphagnum*) is needed to retain and absorb water, as a flood mitigation function (Gauthier et al., 2022; Waddington et al., 2011). Second, the emergence of an acrotelm that covers most of the area, other vegetation types are less likely to form and grow, such as shrubs and trees. These hinder the cooling ability the nature reserve can have for the area, as heatwave mitigation only works when the wetland is not shrub dominated (Worrall et al., 2020). Third, a recovered wetland ecosystem evaporated more water than any other type of land (Bullock & Acreman, 2003). This immense evapotranspiration that occurs in raised bogs is needed to release energy or heat into the atmosphere, to create shade by increased cloudiness and mist, and potentially induce more local precipitation (Hesslerová, 2019.). These effects are needed to mitigate the dry hazards. Fourth, for drought mitigation, it would be best if the wetland is flooded, or at least have a completely saturated soil with high groundwater levels. This will also help the ability of a wetland to stop or slow down the process of a meteorological flood turning into a hydrological flood. Lastly, a drained wetland is more susceptible to wildfires, so if the groundwater levels are not high enough, the wildfire mitigating ability is lower (Kettride, 2017).

Drained or dry peatlands have another risk associated with it. The risk profile for Drenthe highlighted the danger of drought in peatlands, as it will put the fire water supply at risk (VRD, 2024a). Thus, reducing the ability to extinguish wildfires that might already be more likely to be triggered. Moreover, dry peatlands can cause dikes to dry out and consequently lead to floods (VRD, 2024a).

It is also important that policymakers make a clear prioritization of hazards when considering using Bargerveen for climate adaptation. This became apparent when analysing the various hazards, their respective NbS abilities and needs, and their interactions. As Figure 11 from research question 2 shows, there are a lot of interactions between the hazards, the ecosystem services and the effects of the NbS. For instance, strategies to mitigate drought risk, such as water retention, may inadvertently increase flood vulnerability. Moreover, these trade-offs are further complicated when hazards occur as compound hazards, which can place additional strain on the ecosystem.

The risk profile and management plans for Drenthe that were written in accordance with the Act of Safety Regions mainly focus on wildfires, with a smaller focus on droughts and floods. Heatwaves are barely, if at all, mention in those documents. Suggesting that the safety region in which Bargerveen is situated in, finds the increased risk of wildfires, and to a lesser extent floods and droughts, most important. If the safety region where to prioritise these hazards over heatwave mitigation, some interactions are no longer noteworthy or important to keep in mind. For example, droughts that occur together with heatwaves will decrease the cooling ability for heatwaves, as it decreases the amount of moisture in the wetland, and thus decrease the evapotranspiration. This, in turn, decreases the energy/heat released into the atmosphere and decreases the cloud cover and mist which minimizes shade. Moreover, wildfires, floods,

and droughts can all also destroy vegetation in the raised bog, which also decreases the evapotranspiration.

There are still a few undesirable interactions that would still require attention, if the focus is to be placed on floods, droughts, and wildfires. To start, droughts decrease the ability for wildfire mitigation, as soils dry out, and surface and groundwater resources diminish. Wildfires, in turn, also decrease the ability of the wetland to mitigate droughts, as (soil) moisture is vital. Moreover, a heatwave can worsen both drought and wildfires, lowering the ability to fight either phenomenon. To conclude, both droughts and wildfires can lessen the capability to mitigate floods, as they can destroy vegetation and by drying out the soil too much so that water runs off the surface instead of infiltrating.

Fortunately, there are also two desirable interactions that should be used to their full advantage. A drought that occurs before a flood will increase the flood mitigation ability, as there is more room for taking up (flood) water. The drought cannot be too severe however, to avoid surface runoff. Additionally, a flood will saturate the soil fully and strengthen the drought buffering capacity and wildfire mitigation. This saturated soil will also help evapotranspiration, which will help against heatwaves, even though this might not the focus of the province.

6.1.4 Implications of Bargerveen as NbS

When considering using Bargerveen and the German side of the raised bog for climate adaptation in disaster risk management, there are certain considerations that are required. As highlighted in research question 5, the perceptions of the local community on the social and economic roles of Bargerveen directly influence the feasibility and acceptance of using the site for climate adaptation measures. To increase overall motivation in Germany and the Netherlands, the raised bog could be set up for recreational use wherever and whenever possible. This would help to increase the (local) support for nature reserves (Wood et al., 2024). Obviously, it would not always be possible to use the area for recreational use, for example when the reserve would be flooded. Currently, the small German NSG cannot be entered outside of the designated paths, except if the purpose of the protection requires or allows it. Similar rules are set for Bargerveen (Staatsbosbeheer, n.d.). For recreation, you are allowed to walk and cycle on the paths. You can, however, not enter Bargerveen with a horse. The ban on horseback riding in the reserve is a significant source of tension in the community, as many residents struggle to understand the restriction and feel frustrated by it.

Involving residents in decision-making, like finding a solution so that people might be allowed into the reserve with horses, could also increase motivation and support (Paulissen, 2023). According to a broader study on perspectives of Dutch raised bogs concluded that people already feel attached to it and find the landscape type useful (Paulissen et al., 2022). The survey showed that over 83% want the local community to be involved to some degree. This could also be improved informing of the decision, their reasoning, and their impact as some people stated that they do not understand some decisions. Including the local population in decision-making surrounding Bargerveen and its capacity to help with climate adaptation, you also increase their preparedness. Increasing the preparedness of the population is the second goal of the EU Civil Protection Mechanism (CPM) (EC, n.d. -b). The Dutch *Omgevingswet* also states that administrative bodies must consider the societal interest involved when changing or adapting the environment.

The survey results also indicate concerns about developments in and around Bargerveen, particularly regarding potential negative economic impacts. Even though only 6.7% of respondents indicated that changes to Bargerveen negatively impacted their lives, over half (58%) of the mentioned disadvantages to Bargerveen as nature reserve in the community, were about the local economy and employment. Moreover, most concerns for the future were on policy and legislation. For example, concerns on the relationship between local decision-making and farmers, or between the Netherlands and Germany. Another concern that was mentioned relatively often is that agricultural fields and people’s basements are increasingly

being flooded, due to the high groundwater levels needed in Bargerveen. People might not approve of letting the water levels rise even more, which would be vital for Bargerveen to function in DRM.

6.1.5 Political feasibility of Bargerveen as NbS

The political feasibility of utilizing Bargerveen and its German counterpart for disaster risk management as a Nature-Based Solution hinges on effective cross-border cooperation and alignment with regional and EU policies. As discussed in research question 4, the ability to implement DRM strategies that incorporate both the Dutch and German portions of the raised bog will depend on the political will to collaborate. Under many different policies, both the Netherlands and Germany have vowed to increase their efforts in DRM, by increasing resilience and enhance preparedness. For example, the Sendai Framework and the EU Civil Protection Mechanism. Using the raised bog could entail only using Bargerveen, or also including the part of the wetland that is situated in Germany. When choosing the latter option, the need for transboundary cooperation increases. The Sendai Framework encourages transboundary cooperation to grow resilience and reduce disaster risk.

Germany and the Netherlands work together on cross-border issues relatively often, for example during the 2021 floods. Despite working together often and civilly, the response to 2021 demonstrated significant shortcomings in cooperation and coordination (Hagenlocher et al., 2023). In a paper from the United Nations University, they reflected on this disaster. They concluded that "One of the most important lessons from the 2021 floods was the lack of joint coordination across levels and sectors, even within the affected countries." (Hagenlocher et al., 2023, p. 16). They advise that the three countries involved, including Germany and the Netherlands, should improve cross-border cooperation, even outside of crises situations. It would be wise to cooperate on potential DRM projects before the disasters strikes, by for example, combining efforts to use the complete raised bog for climate adaptation and DRM.

The EU Strategy on Adaptation to Climate Change directive could help to facilitate the use of the raised bog for climate adaptation. If Bargerveen were to be used as a climate adaptation solution, several adjustments would be required to align with the EU strategy. The reserve's capacity to mitigate climate-related risks would need to be optimized. This could involve enhancing its water retention capabilities, maintaining high groundwater levels, and/or restoring degraded parts of the wetlands, particularly on the German side. This would be made easier if the German nature park would be classified as a *naturschutzgebiet (NSG)*, like *Dalum-Wietmarscher Moor*, instead. The systemic approach would require stronger cross-border collaboration between Germany and the Netherlands, while including other stakeholders such as *Staatsbosbeheer*. Finally, Bargerveen's role as an adaptation solution would need to be embedded in broader regional and national climate adaptation policies, ensuring long-term support and alignment with EU objectives for resilience by 2050.

6.2 Limitations to the study

While this study may provide valuable insights into the role of wetland ecosystems in disaster risk management, several limitations should be acknowledged. These limitations stem from constraints in data availability, methodological choices, and scope/time restrictions. Moreover, acknowledging these challenges highlights areas for potential improvement and future research directions.

For the data analysis of the weather and the model of the future groundwater levels, there were some data limitations. The use of groundwater to simulate the future state of Bargerveen was convenient since groundwater turned out to be one of the most limiting factors in recovery. However, to show the health or ecological state of Bargerveen under different future scenarios, the use of peat or moss growth could have been a stronger indicator. This data was, unfortunately, not available for Bargerveen. Moreover, there were a lot of groundwater data points in Bargerveen, all owned by different parties and used differently. This makes it

hard to say that the conclusions from the model with the chosen data points, are representative to the entire groundwater levels in Bargerveen. The groundwater and surface water levels lacked a defined target level, making it difficult to assess whether observed levels were too low for healthy raised bog. The conclusions were, thus, based on that groundwater levels are currently not high and stable enough, so any lower, like the scenarios indicate, suggests a negative trend. Lastly, the weather data used in the model was from the Hoogeveen KNMI location, which is about 30 km away from the wetland, which may introduce inaccuracies. There was no closer KNMI location that provided future scenario data to use instead.

Methodological constraints arose from two different parts of the study. First, the groundwater model could have been made more reliable if additional variables were included or used, such as peat growth. There might also be uncertainties in the trend analysis due to length or consistency of used historical data. The four different groundwater data points did not show the same trend, so more or other data points could have used. Additionally, a more advanced model (e.g. using MODFLOW in Python) could have improved accuracy.

Second, the survey did not get sufficient responses to make statistically representative conclusions about the entire local population near Bargerveen. Some survey questions could have also been phrased differently to improve correlation analysis or encourage more open-ended responses. Not many correlations could be proven between the questions in the survey. Reasons for this could be that too few people filled in the survey, the group was too varied or not varied enough, the questions were asked in a wrong way, or alternatively no such correlations exist. By sharing the survey in the newsletter of Bargerveen-Schoonebeek, the survey responses may not fully represent the diversity of views within the local population. For instance, individuals with strong environmental concerns or more knowledge about wetland management may have been more likely to participate. Certain demographic or social groups may be underrepresented in the survey sample, such as local farmers or individuals from non-environmentally active communities, potentially leading to missing perspectives and a sampling bias. The few responses with noticeably different answers were contacted for follow-up questions, and they were local farmers, highlighting that the inclusion of more farmers, might have altered the results of the survey.

The study was limited to Bargerveen. Comparing results with other similar recovered wetlands or raised bogs could have strengthened the conclusions. For example, research on wetlands in Ireland or Estonia could have been used to compare findings with. Due to scope and time constraints, this was not feasible. Another scope constraint was the addition of studying water quality benefits that wetlands can give. Wetlands can improve the water quality by filtering pollutants (Lui et al., 2023). Due to climate change, the supply of clean drinking water is under stress and action is needed to prevent a drinking water shortage by 2030 (RIVM, 2023). The risk profile of Drenthe does mention clean drinking water, but only how they are currently protecting it, and not that there is a risk in the future. This suggests that this disaster is not most pressing issue for them. This could cause a disaster in the future, and, thus, could have been added to the disasters assessed in this study. Time constraints also prevented more in-depth interviews with, for example, farmers or policymakers, which could have added more insights.

6.3 Contextualizing the findings: Raised bog as carbon storage

According to the nature management plan (*Natuurbeheerplan*) of Drenthe, raised bogs (such as Bargerveen) will be used to hold CO_2 to reduce the net carbon emissions (Provincie Drenthe, 2024). Indirectly, the sequestration of CO_2 will also mitigate the risk of (compounding) hazards, by decreasing the amount of carbon in the climate system and thus, the impacts of climate change. In a chapter by Harenda et al. (2018) in *Interdisciplinary Approaches for Sustainable Development Goals*, they describe the role of peatlands and carbon storage in climate change. Carbon is stored in peatlands by photosynthesis and released by respiration. Since peatlands have high humidity levels in the soil, the conditions are anoxic,

slowing down the decomposition of organic matter, and thus, slowing down the release of carbon back into the atmosphere. Moreover, they found that the highest sequestration rate is in peatlands with *Sphagnum* moss, whereas the lowest rate was found in forested peatlands with low water tables.

Multiple studies were devoted to carbon storage in restored or rewetted peatlands. They all conclude the same things, namely rewetted peatlands act as a carbon sink, while drained peatlands act as a carbon source (Wilson et al., 2022; Swenson et al., 2019). Moreover, rewetted raised bogs reduce emissions by 75% compared to intensive grassland use (Huth et al., 2022). It is significant to point out, however, that methane emissions increase with rewetting (Wilson et al., 2022; Huth et al., 2022; Swenson et al., 2019). Wilson et al. (2022) also noted that in the highest carbon emission scenario, the rewetted sites will not reach a cooling phase, but under low emission scenarios, they do. In the worst-case scenario, in a study on raised bog restoration, the sites emit over 200 g of carbon m^{-2} yr^{-1}, and in the best-case scenario. They store 58 g of carbon m^{-2} yr^{-1}.

To get the best result, a high-water table and *Sphagnum* moss are essential to the process (Swenson et al., 2019). This indicates that rewetting and restoring peatlands should happen quickly and properly to ensure carbon storage and a shift towards a cooling climate. Huth et al. (2022) found that when you combine rewetting with topsoil removal, the CO_2 emission remain zero or turn negative, while methane emissions stay low. Hence, topsoil removal, rewetting, and *Sphagnum* introduction together are an effective climate mitigation strategy, as topsoil removal helps to create the right conditions for the moss to grow (Huth et al., 2022). Positively, Heijmans et al. (2013) concluded that under the current climate, peat bog vegetation is relatively resilient to drought events. Peat bog is, however, very sensitive to an increase in temperature. Hence, under the different future scenarios, that all indicate some level of warming, vegetation can shift, meaning that other vegetation than moss can become dominant. This could impact the mitigating effects the wetlands have, as the cooling and drought resistant affects rely on high evapotranspiration rates and no shrub coverage.

7. Conclusion and recommendation

Utilizing wetlands as nature-based solutions in disaster risk management

Wetland ecosystems, particularly raised bogs such as Bargerveen, can play a crucial role in disaster risk management by mitigating the impacts of (compound) natural hazards exacerbated by climate change. These wetlands regulate hydrological conditions by acting as natural sponges, absorbing excess precipitation during periods of heavy rainfall, and gradually releasing stored water during droughts, thereby reducing both flood and drought risk. Furthermore, the high evapotranspiration rates and moisture levels of wetlands can help protect the community against heatwaves and wildfires.

By integrating wetland conservation and restoration into climate adaptation strategies, wetlands can serve as nature-based solutions that enhance regional resilience. Moreover, the policy evaluation highlights that existing Dutch, German, and European frameworks support wetland protection and cross-border collaboration between Germany and the Netherlands. With increased community engagement and informing, and economic incentives where needed, the local support for a wetland-based disaster risk mitigation strategy could be boosted. Therefore, optimizing wetland management for disaster risk reduction requires a combination of strengthened ecological restoration efforts, policy alignment, and stakeholder collaboration.

Recommendations

To support future wetland restoration and effective disaster risk management, further research should focus on examining cross-border initiatives between the Netherlands and Germany. Different existing or proposed initiatives could offer valuable insights into the challenges and opportunities that raise from transboundary projects. For example, further examination could help understand why the transboundary park project *International Naturpark Bourtanger Moor* failed and what is to learn from it. Moreover, by more effective collaborations on DRM, disasters like the 2021 floods could potentially be prevented in the future.

Further research is also necessary to explore the long-term adaptability of wetlands like Bargerveen under various climate and socio-economic scenarios, such as the Shared Socioeconomic Pathways (SSPs). There is limited relevant research on how (recovered) wetlands such as Bargerveen, will adapt to long-term climatic changes. Presently, the restoration and management of wetlands, including Bargerveen, are based on the conditions of the current or past climate. So, most knowledge on the conditions needed to fully recover a wetland is with the current or past climate in mind. It remains uncertain if Bargerveen, for example, will continue to thrive in altered climatic conditions when fully recovered. Furthermore, it would be interesting to study how different socio-economic developments would impact the potential of NbS to mitigate hazards.

Lastly, when adapting Bargerveen, with or without the German side, the implications of increasing the water levels should be taken studied more and considered. Currently, there are already complaints of flooded agricultural fields and basements in the direct surrounding of the nature reserve. It has been a particularly wet year(s), but the groundwater levels are not yet as high as hoped, so further consequences, economic or otherwise, should be studied. Future studies should also explore other modelling approaches to improve accuracy of predictions regarding the water levels under changing climatic conditions. For this, long-term monitoring of climate data and ecological indicates, next to hydrological data, might be needed.

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9. Annex

Annex A: Use of ChatGPT

ChatGPT was used to help with the steps to perform the linear regression analysis, the code to improve the images of the SPI, to give me prompts for the survey, and to do a final spell/grammar check (with Grammarly).

Annex B: Survey response area

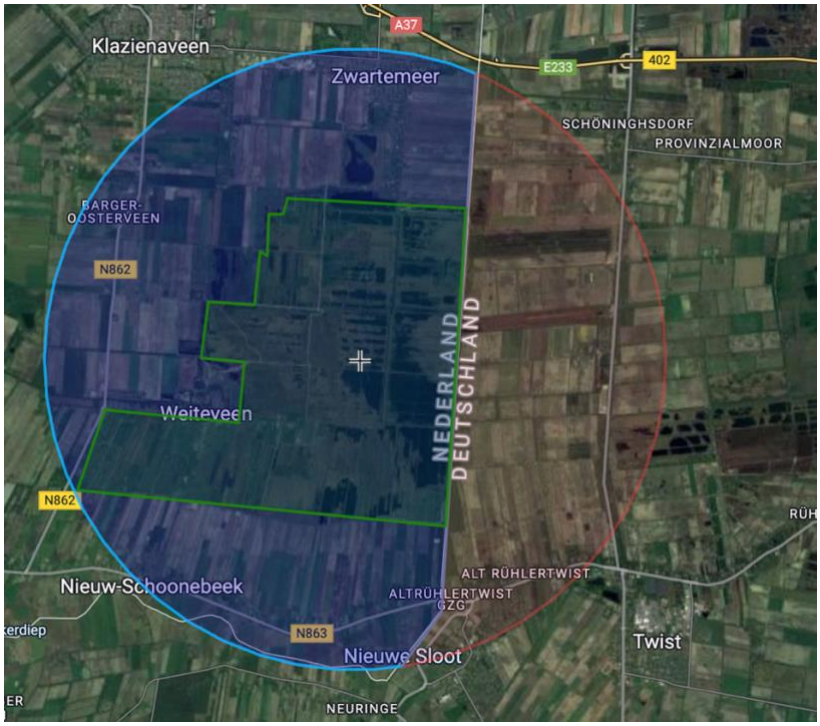

Figure 2. Five km radius around Bargerveen. Bargerveen is in green. The red area is not used, since it falls in Germany.

Annex C: The Survey

Invloeden van Bargerveen op de lokale gemeenschap

Bedankt voor uw deelname aan dit onderzoek!

Deze enquête maakt deel uit van een masterscriptie voor de opleiding Climate Studies aan de Universiteit van Wageningen. Het doel van dit onderzoek is om inzicht te krijgen in de sociale en economische impact van de ontwikkelingen rondom het natuurgebied Bargerveen. Uw antwoorden helpen ons beter te begrijpen hoe de veranderingen in Bargerveen de lokale gemeenschap beïnvloeden en wat uw perspectieven zijn op de huidige en toekomstige ontwikkelingen.

Uw deelname is anoniem en de antwoorden worden vertrouwelijk behandeld. Het invullen van de vragenlijst duurt ongeveer 5-10 minuten.

Alvast hartelijk dank voor uw tijd en bijdrage aan dit onderzoek!

Mocht je vragen of opmerkingen hebben, kunt u mij bereiken op roosmarijn.heesterbeek@wur.nl

roosmarijnheesterbeek@gmail.com Ander account

Niet gedeeld

* Verplichte vraag

Geeft u toestemming om uw antwoorden te gebruiken voor onderzoeksdoeleinden? *

Selecteer alstublieft "Ja" om toestemming te geven voor het gebruik van uw antwoorden in dit onderzoek.

- ◯ Ja, ik geef toestemming voor het gebruik van mijn antwoorden.
- ◯ Nee, ik geef geen toestemming.

Volgende Formulier wissen

Verzend nooit wachtwoorden via Google Formulieren.

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Does this form look suspicious? Rapport

Persoonlijke informatie

In dit deel stellen we enkele vragen over uw achtergrond. Deze informatie helpt ons te begrijpen hoe verschillende groepen de ontwikkelingen in en rond Bargerveen ervaren. Alle antwoorden blijven anoniem.

Wat is uw woonplaats? *

- ◯ Amsterdamscheveld
- ◯ Bargeres
- ◯ Barger-Compascuum
- ◯ Barger-Oosterveen
- ◯ Emmen
- ◯ Erica
- ◯ Klazienaveen
- ◯ Nieuw-Amsterdam
- ◯ Nieuw-Schoonebeek
- ◯ Schoonebeek
- ◯ Weiteveen
- ◯ Zwartemeer
- ◯ Anders: _____

Hoe lang woont u al in de buurt van Bargerveen? *

- ◯ Minder dan 1 jaar
- ◯ 1-5 jaar
- ◯ 6-10 jaar
- ◯ meer dan 10 jaar


Hoe vaak bezoekt u het natuurgebied Bargerveen? *
Nooit
Zelden (minder dan eens per kwartaal)
Soms (ongeveer 1 keer per maand)
Regelmatig (Meerdere keren per maand, of wekelijks)
Vaak (vaker dan 1 keer per week)
Vorige
Volgende
Formulier wissen

Uw ervaringen en perspectieven op Bargerveen

Dit deel richt zich op uw ervaringen met- en meningen over de veranderingen in Bargerveen in de afgelopen jaren. Uw inzichten zijn waardevol om de sociale en economische impact van deze ontwikkelingen op de lokale gemeenschap te begrijpen.

Hoe is uw leven veranderd door de ontwikkelingen en veranderingen rondom Bargerveen in de afgelopen jaren? *

	1	2	3	4	5	
Zeer negatief (De veranderingen hebben mijn leven sterk negatief beïnvloed, zoals economische nadelen, beperkingen in gebruik van land, of minder toegang tot natuurgebieden.)	○	○	○	○	○	Zeer positief (De veranderingen hebben mijn leven sterk verbeterd)

Welke voordelen denkt u dat Bargerveen als beschermd natuurgebied op dit moment biedt voor de lokale gemeenschap? (Meerdere antwoorden mogelijk) *

- [ ] Ik denk dat er geen voordelen zijn
- [ ] Verhoogde biodiversiteit
- [ ] Verbeterde waterkwaliteit
- [ ] Verbetering van recreatiemogelijkheden
- [ ] Meer recreatiemogelijkheden voor de gemeenschap
- [ ] Verhoogde landbouwproductiviteit
- [ ] Bescherming tegen (lokale) overstromingen
- [ ] Bescherming tegen (lokale) droogte
- [ ] Minder negatieve effecten van hittegolven
- [ ] Minder kans op (lokale) natuurbrand
- [ ] Positieve invloed op de lokale economie
- [ ] Anders: _____

Welke nadelen denkt u dat Bargerveen als beschermd natuurgebied op dit moment biedt voor de lokale gemeenschap? (Meerdere antwoorden mogelijk) *

- [ ] Ik denk dat er geen nadelen zijn
- [ ] Verlies van landbouwgrond of landbouwverdiensten
- [ ] Negatieve invloed op de lokale economie
- [ ] Verandering in landgebruik
- [ ] Verminderde werkgelegenheid
- [ ] Kosten van het onderhoud van het natuurgebied
- [ ] Verminderde waterbeschikbaarheid voor bijvoorbeeld landbouw
- [ ] Verhoogde kans op wateroverlast en overstromingen
- [ ] Verminderde biodiversiteit door menselijke interventie
- [ ] Beperking van recreatiemogelijkheiden voor de gemeenschap
- [ ] Anders: _____

Wat zijn uw eventuele zorgen met betrekking tot de toekomstige ontwikkelingen in Bargerveen? (Meerdere antwoorden mogelijk) *

- [ ] Ik heb geen zorgen
- [ ] Verlies van landbouwgrond en/of verdiensten
- [ ] Verlies van cultureel erfgoed
- [ ] Negatieve veranderingen in lokale regelgeving (bijvoorbeeld het wegvallen van subsidies)
- [ ] Minder samenwerking tussen de omgeving en natuurbeheer
- [ ] Minder samenwerking tussen Duitsland en Nederland over Bargerveen
- [ ] Negatieve effecten op de natuur (bijvoorbeeld minder biodiversiteit, of slechtere waterkwaliteit)
- [ ] Verminderde waterbeschikbaarheid voor bijvoorbeeld landbouw
- [ ] Anders: _____

Wat zijn uw eventuele positieve verwachtingen met betrekking tot de toekomstige ontwikkelingen in Bargerveen? (Meerdere antwoorden mogelijk) *

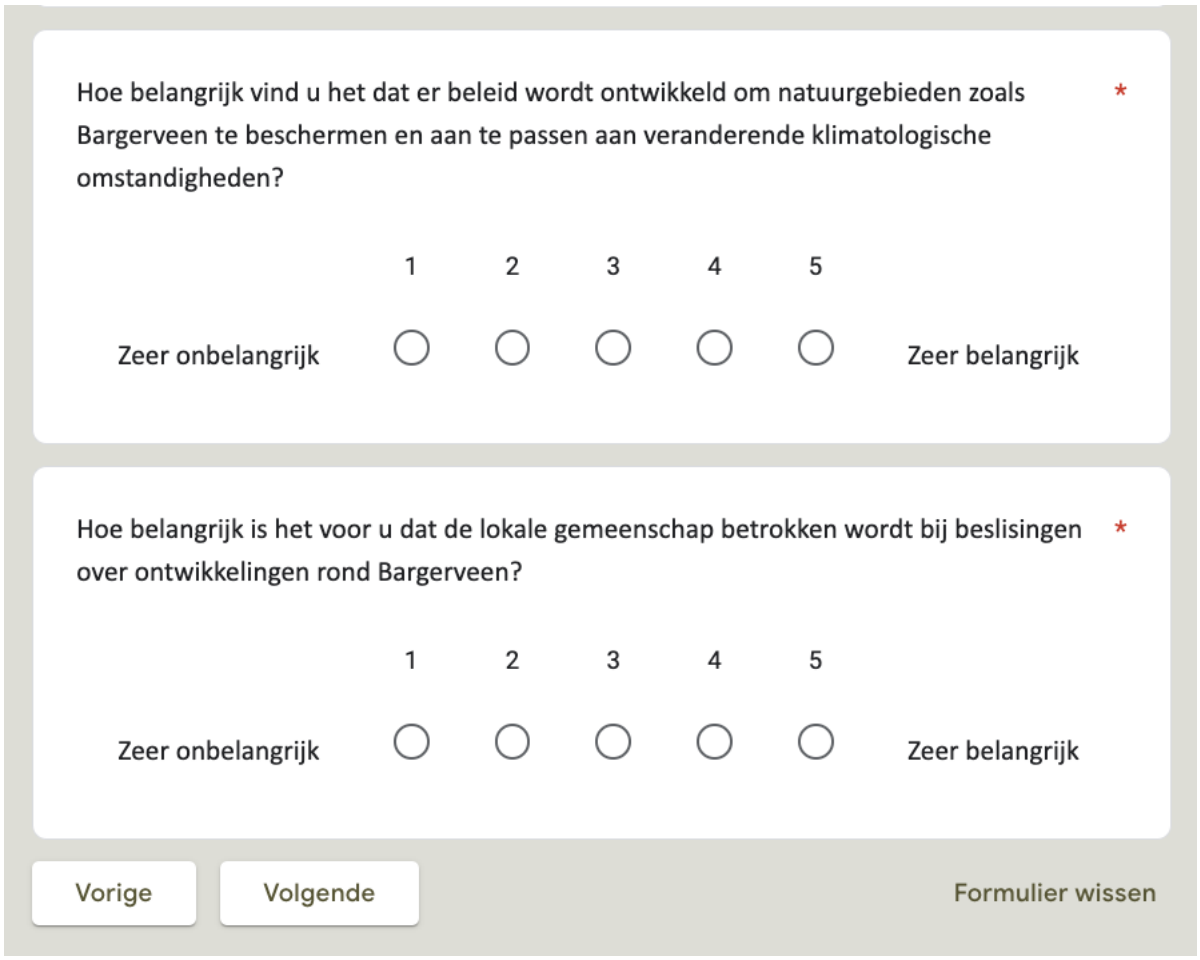
- [ ] Ik heb geen positieve verwachtigingen
- [ ] Positieve effecten op natuur (bijvoorbeeld meer biodiversiteit, of betere luchtkwaliteit)
- [ ] Economische groei door bijvoorbeeld toerisme
- [ ] Behoud van cultureel erfgoed in de omgeving
- [ ] Positieve veranderingen in de lokale regelgeving (bijvoorbeeld meer subsidies)
- [ ] Verhoogde samenwerking tussen de omgeving en natuurbeheer
- [ ] Verhoogde samenwerking tussen Duitsland en Nederland over Bargerveen
- [ ] Verhoogde beschikbaarheid van water voor de omgeving
- [ ] Anders: _____

Hoe ervaart u de huidige toestand van het natuurgebied Bargerveen in termen van biodiversiteit en waterhuishouding? *

- ◯ Weet ik niet / kan ik niet beantwoorden
- ◯ Zeer negatief
- ◯ Negatief
- ◯ Neutraal
- ◯ Positief
- ◯ Zeer positief

In welke mate denkt u dat natuurgebieden zoals Bargerveen bijdragen aan het beperken van gevolgen van extreme weersomstandigheden (bijv. overstromingen, droogtes)? *

	1	2	3	4	5	
Helemaal niet	◯	◯	◯	◯	◯	In zeer hoge mate



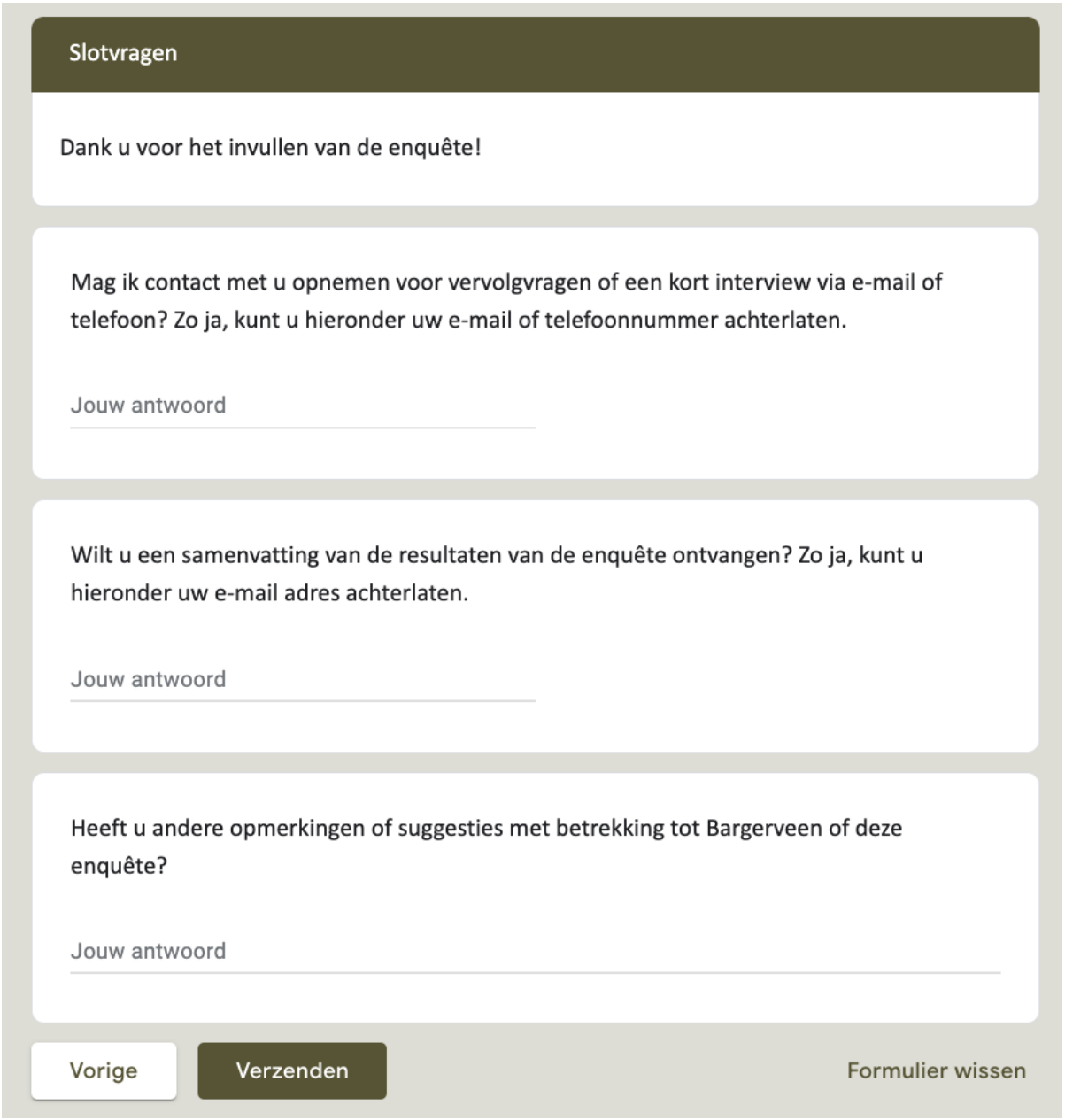
Hoe belangrijk vind u het dat er beleid wordt ontwikkeld om natuurgebieden zoals Bargerveen te beschermen en aan te passen aan veranderende klimatologische omstandigheden? *

	1	2	3	4	5	
Zeer onbelangrijk	○	○	○	○	○	Zeer belangrijk

Hoe belangrijk is het voor u dat de lokale gemeenschap betrokken wordt bij beslisingen over ontwikkelingen rond Bargerveen? *

	1	2	3	4	5	
Zeer onbelangrijk	○	○	○	○	○	Zeer belangrijk

Vorige Volgende Formulier wissen



Slotvragen

Dank u voor het invullen van de enquête!

Mag ik contact met u opnemen voor vervolgvragen of een kort interview via e-mail of telefoon? Zo ja, kunt u hieronder uw e-mail of telefoonnummer achterlaten.

Jouw antwoord

Wilt u een samenvatting van de resultaten van de enquête ontvangen? Zo ja, kunt u hieronder uw e-mail adres achterlaten.

Jouw antwoord

Heeft u andere opmerkingen of suggesties met betrekking tot Bargerveen of deze enquête?

Jouw antwoord

Vorige Verzenden Formulier wissen

Annex D: Groundwater level scatterplot with trendlines

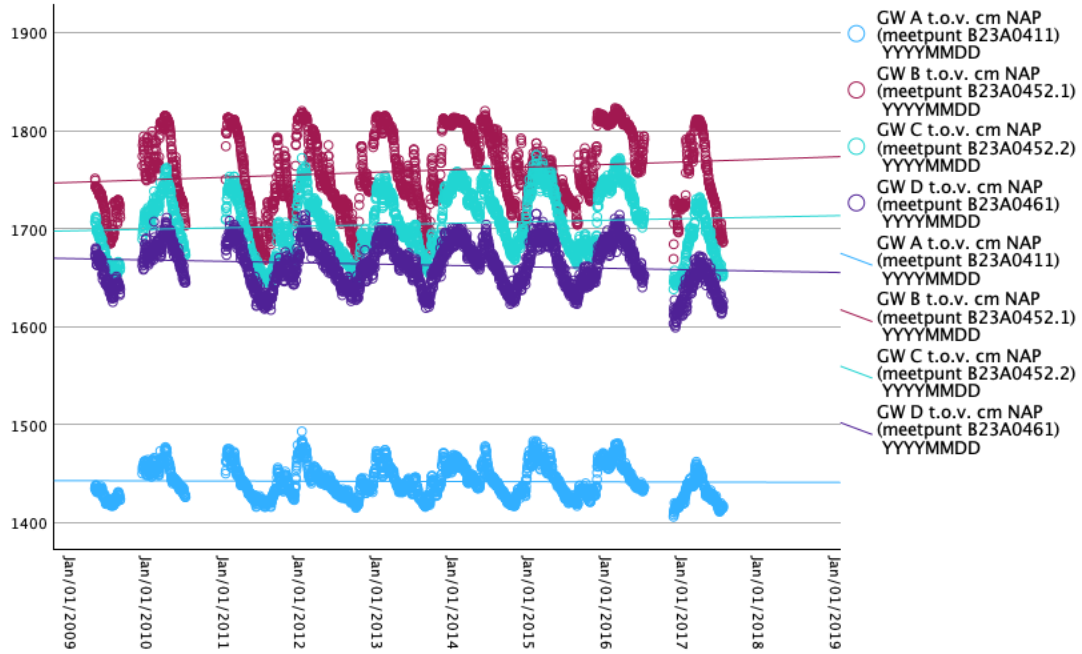


Figure 3. Scatterplots with trendlines of the various groundwater datasets.

Annex E: Climate data results

Table 1 Spearman's test and trend results from Eelde

Variable 1	Variable 2	Spearman's rho	p-value	R^2 Linear
Time	Precipitation	-0.039	<0.001	5.48E-5
Time	Temperature	0.103	<0.001	0.013
Time	Detrended Precipitation	-0.017	0.004	4.87E-5
Time	Detrended Temperature	0.190	<0.001	0.038

Table 2 Spearman's test and trend results from Hoogeveen

Variable 1	Variable 2	Spearman's rho	p-value	R^2 Linear
Time	Precipitation	0.011	0.120	7.79E-9
Time	Temperature	0.069	<0.001	0.006
Time	Detrended Precipitation	0.012	0.106	2.94E-7
Time	Detrended Temperature	0.107	<0.001	0.013

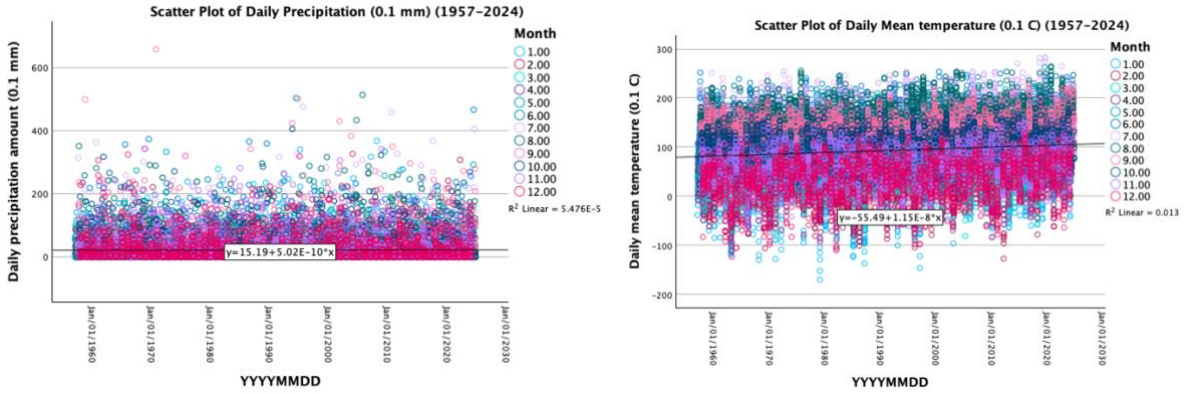
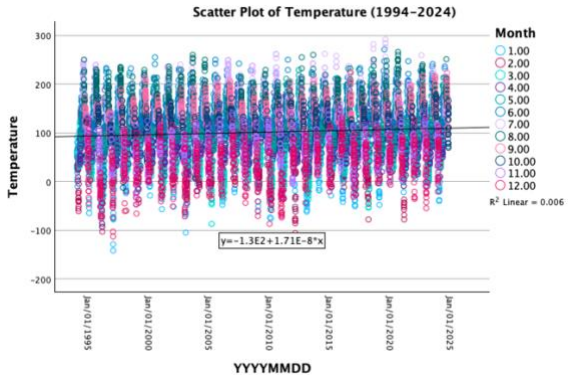


Figure 4 and 5. Scatterplots of weather data Eelde



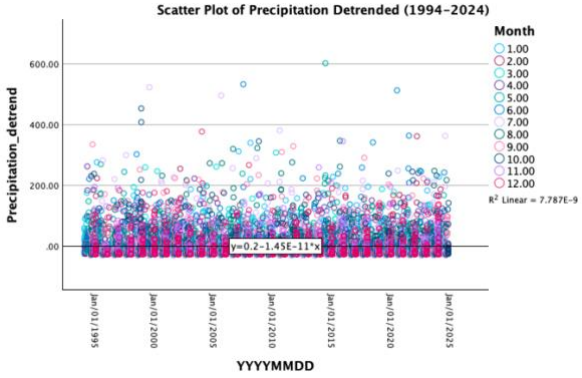
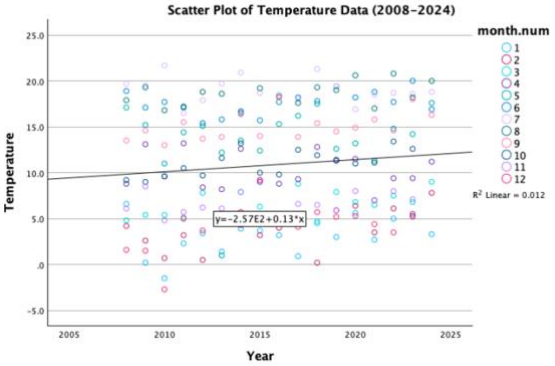


Figure 6 and 7. Scatterplots of weather data Hoogeveen



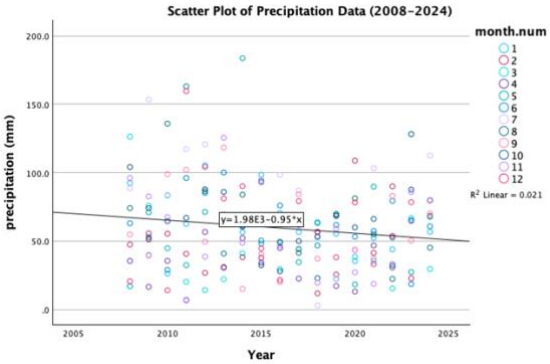


Figure 8 and 9. Scatterplots of weather data Emmen

Annex F: Groundwater model results

Table 3 Results from Spearman's correlation test between groundwater and the independent variables. Red indicates insignificant correlation.

Groundwater dataset	Independent variable	Correlation Coefficient (Spearman's R)	Significance (p-value)
A	**Temperature**	-0.515	<0.001
	Precipitation	0.114	<0.001
	Humidity	0.094	<0.001
	Surface water level	-0.898	<0.001
B	**Temperature**	-0.381	<0.001
	Precipitation	0.110	<0.001
	Humidity	0.057	0.011
	Surface water level	-0.807	<0.001
C	**Temperature**	-0.415	<0.001
	Precipitation	0.103	<0.001
	Humidity	**-0.023**	**0.177**
	Surface water level	-0.947	<0.001
D	**Temperature**	-0.470	<0.001
	Precipitation	0.103	<0.001
	Humidity	**-0.001**	**0.487**
	Surface water level	-0.926	<0.001

Table 4 Results of the linear regression test between the dependent and independent variables.

GW dataset	R square	Significance (p-value)
A	79.1 %	<0.001
B	69.3 %	<0.001
C	89.3 %	<0.001

D	85.8 %	<0.001

Table 5 Predicting surface water levels (results)

Variable	**Spearman's rho**	**Significance**	**Coefficient B**	**significance**
Temperature	0.499	<0.001	0.097	<0.001
precipitation	-0.062	0.006	-0.022	<0.001
Humidity	0.044	0.038	0.301	<0.001

R square was 0.191 with <0.001 significance.
Final equation $Y = 60.022 + (0.097 * T) - (0.022 * P) + (0.301 * H)$

Average surface water in different predictions: (Standard deviation is around 5.5-5.7)

- Ld: 94.98
- Ln: 94.99
- Hd: 98.42
- Hn: 98.67

Validation:
Correlation 0.680 with p<0.001.
Residual histogram skewed to the left but has a mean of 2.79.

Line graphs of groundwater predictions

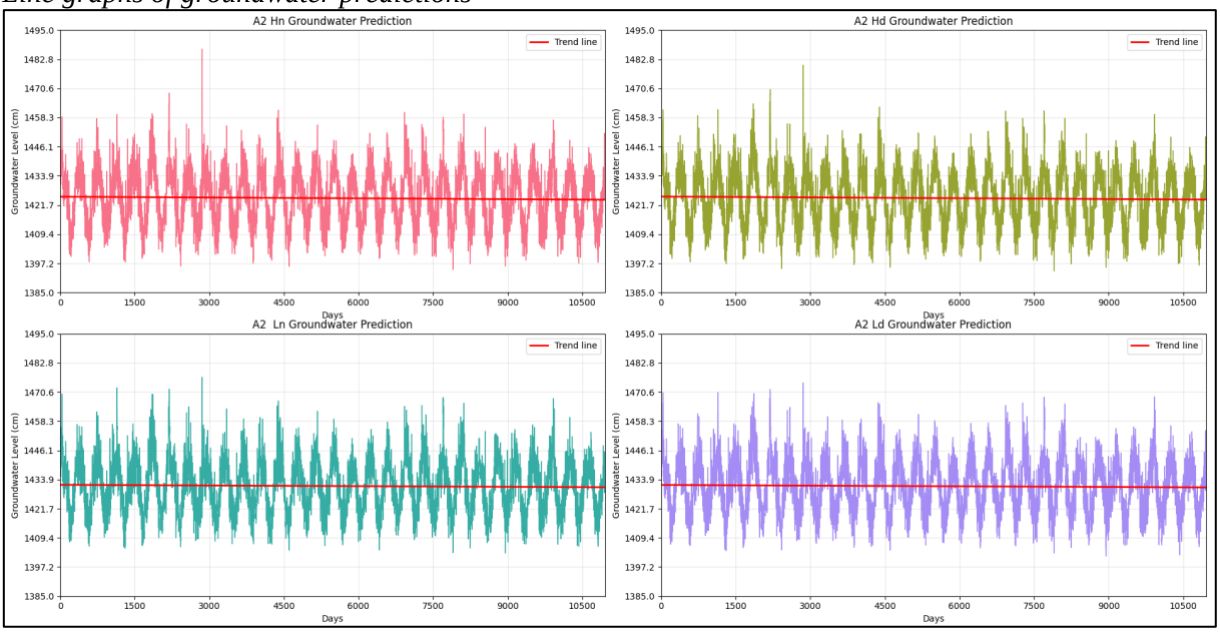


Figure 10. Line graphs of groundwater model A with all scenarios

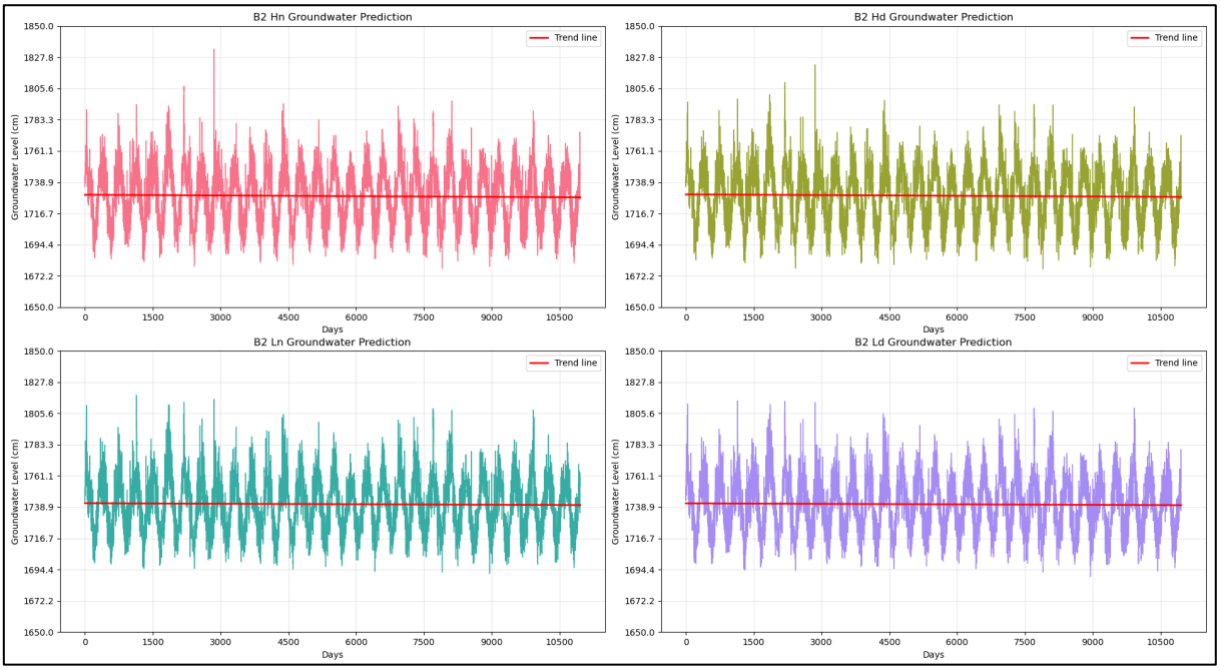


Figure 11. Line graphs of groundwater model B with all scenarios

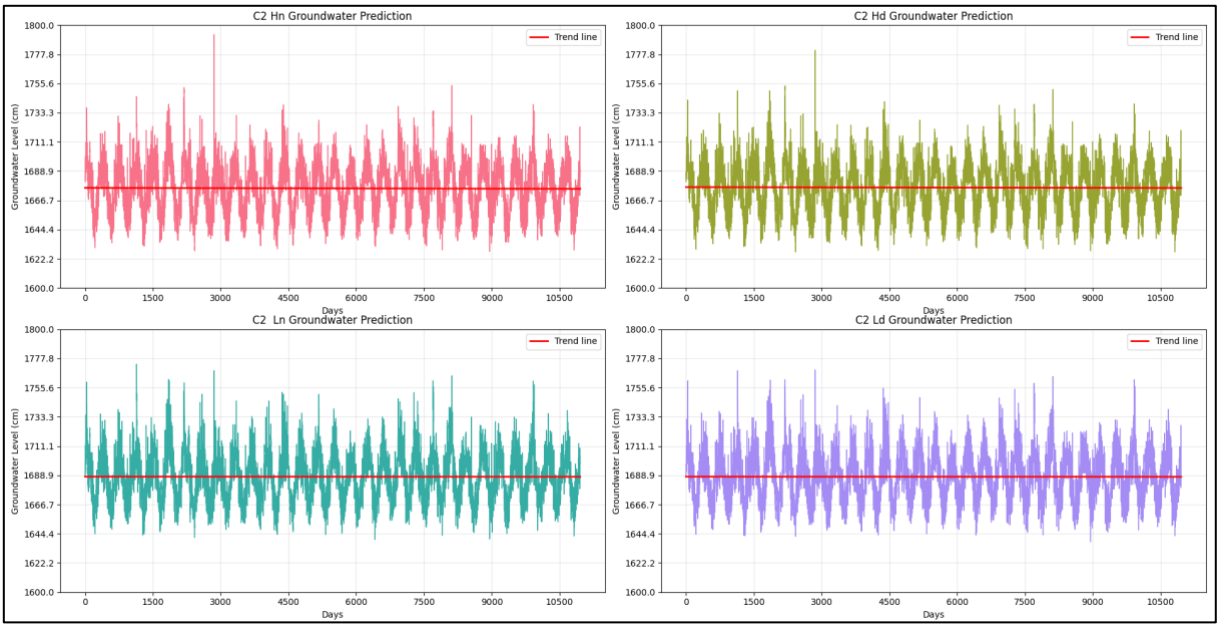


Figure 12. Line graphs of groundwater model C with all scenarios

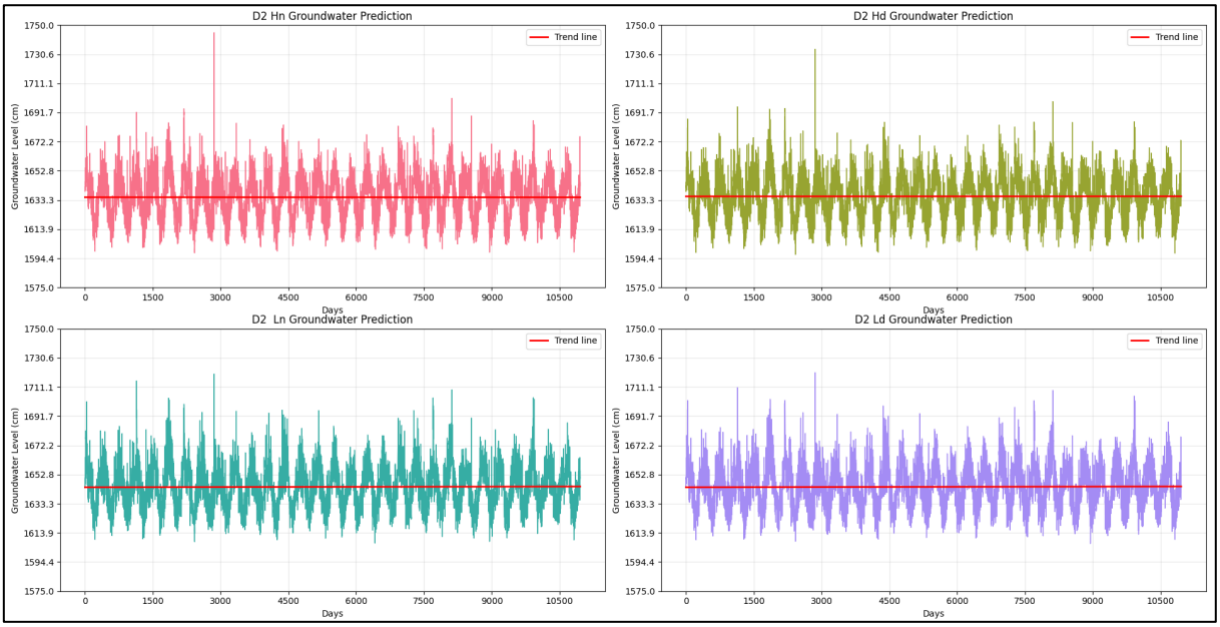


Figure 13. Line graphs of groundwater model D with all scenarios

Annex G: Additional survey results

Table 6 Correlation results with entire dataset (N=60)

Correlations

			Years living near Bargerveen	Frequency of visits to Bargerveen	Perception of biodiversity and water management in Bargerveen	Contribution of Bargerveen to mitigating extreme weather	Importance of policies for protecting and adapting Bargerveen to climate change	Importance of involving the local community in decisions
Spearman's rho	Years living near Bargerveen	Correlation Coefficient	1.000	.039	.052	-.032	-.063	.180
		Sig. (1-tailed)	.	.385	.347	.404	.316	.084
		N	60	60	60	60	60	60
	Frequency of visits to Bargerveen	Correlation Coefficient	.039	1.000	.081	.085	-.009	.059
		Sig. (1-tailed)	.385	.	.269	.259	.473	.328
		N	60	60	60	60	60	60
	Perception of biodiversity and water management in Bargerveen	Correlation Coefficient	.052	.081	1.000	.433**	.202	.069
		Sig. (1-tailed)	.347	.269	.	<.001	.061	.301
		N	60	60	60	60	60	60
	Contribution of Bargerveen to mitigating extreme weather	Correlation Coefficient	-.032	.085	.433**	1.000	.494**	-.029
		Sig. (1-tailed)	.404	.259	<.001	.	<.001	.412
		N	60	60	60	60	60	60
	Importance of policies for protecting and adapting Bargerveen to climate change	Correlation Coefficient	-.063	-.009	.202	.494**	1.000	.027
		Sig. (1-tailed)	.316	.473	.061	<.001	.	.420
		N	60	60	60	60	60	60
	Importance of involving the local community in decisions	Correlation Coefficient	.180	.059	.069	-.029	.027	1.000
		Sig. (1-tailed)	.084	.328	.301	.412	.420	.
		N	60	60	60	60	60	60

**. Correlation is significant at the 0.01 level (1-tailed).

Table 7 Correlation results with only responses of the Newsletter (N=47)

Correlations

			Years living near Bargerveen	Frequency of visits to Bargerveen	Life changes due to Bargerveen developments	Perception of biodiversity and water management in Bargerveen	Contribution of Bargerveen to mitigating extreme weather	Importance of policies for protecting and adapting Bargerveen to climate change	Importance of involving the local community in decisions
Spearman's rho	Years living near Bargerveen	Correlation Coefficient	1.000	.074	-.113	.129	-.025	-.024	.144
		Sig. (1-tailed)	.	.311	.224	.193	.434	.436	.168
		N	47	47	47	47	47	47	47
	Frequency of visits to Bargerveen	Correlation Coefficient	.074	1.000	.350**	.045	.072	.009	.056
		Sig. (1-tailed)	.311	.	.008	.383	.316	.476	.353
		N	47	47	47	47	47	47	47
	Life changes due to Bargerveen developments	Correlation Coefficient	-.113	.350**	1.000	.503**	.475**	.272*	.106
		Sig. (1-tailed)	.224	.008	.	<.001	<.001	.032	.239
		N	47	47	47	47	47	47	47
	Perception of biodiversity and water management in Bargerveen	Correlation Coefficient	.129	.045	.503**	1.000	.362**	.158	.069
		Sig. (1-tailed)	.193	.383	<.001	.	.006	.144	.321
		N	47	47	47	47	47	47	47
	Contribution of Bargerveen to mitigating extreme weather	Correlation Coefficient	-.025	.072	.475**	.362**	1.000	.489**	-.068
		Sig. (1-tailed)	.434	.316	<.001	.006	.	<.001	.324
		N	47	47	47	47	47	47	47
	Importance of policies for protecting and adapting Bargerveen to climate change	Correlation Coefficient	-.024	.009	.272*	.158	.489**	1.000	.069
		Sig. (1-tailed)	.436	.476	.032	.144	<.001	.	.322
		N	47	47	47	47	47	47	47
	Importance of involving the local community in decisions	Correlation Coefficient	.144	.056	.106	.069	-.068	.069	1.000
		Sig. (1-tailed)	.168	.353	.239	.321	.324	.322	.
		N	47	47	47	47	47	47	47

**. Correlation is significant at the 0.01 level (1-tailed).

*. Correlation is significant at the 0.05 level (1-tailed).